JOURNAL OF

# Petroleum Technology

Volume 1 DECEMBER, 1949 Number 12

PRINCET LIBR JAN 3 RECEIVED

TABLE OF CONTENTS

***Petroleum Branch — Section 1***

GUEST EDITORIAL, by H. H. Kaveler . . . . . 5

RECENT CANADIAN OIL DEVELOPMENTS, by J. D. Gustafson . . . . 8

PETROLEUM BRANCH EXECUTIVE COMMITTEE OPEN MEETING . . . . 16

NEWS OF LOCAL SECTIONS . . . . . 26

STUDENT ACTIVITIES . . . . . 39

Professional Cards . . . . 40 Employment Notices . . . . 42

***AIME News — Section 2***

AIME ANNUAL MEETING . . . . . 318

AIME MEDALISTS FOR 1950 . . . . . 320

Local Section Notes . . . . 323 Personals . . . . . 324

Obituaries . . . . . 330 Membership . . . . . 331

***Petroleum Transactions***

T.P. 2767 WAVE FORCES COMPUTED FOR A TYPICAL OFFSHORE DRILLING SITE, by Paul L. Horrer . . . . . 299

T.P. 2732 THE APPLICATION OF THE LAPLACE TRANSFORMATION TO FLOW PROBLEMS IN RESERVOIRS, by A. F. van Everdingen and W. Hurst . . . . . 305

# NAVARRO SAND IN CHARLOTTE FIELD ATASCOSA COUNTY, TEXAS

Mud (Water & Clay): $R_m$ = 1.00 ohm at BHT
Bit size: 7⅞"
Spacings: AM = 16"
AM' = 63"
AO = 24'

This is the third in a series of interpreted electrical logs from identified formations and fields which Schlumberger will reproduce in this publication. If you would like to keep this entire series, please write to us on your letterhead and we will be glad to send you a reprint of this log (and preceding logs in this series) with a binder in which you may file subsequent logs as they are published. This series is made possible through the courtesy and cooperation of the oil operators who have released these logs.

3

## LOG ANALYSIS

**1) Water saturation S**

This sand is relatively clean in the first 15' and is found highly interbedded with shale below the upper section.

The value of 8 ohms at level A given by the 63" Normal when corrected will result in $R_t$ = 12 ohms approximately.

$R_o$ = 2 ohms in neighboring wells.

In A: $S = \sqrt{\frac{2}{12}} = 41\%$

**2) Formation water resistivity $R_w$**

With $SP = -70 \log_{10} \frac{R_m}{R_w}$ and SP = —65 mv.,

$R_w$ = 0.12 at BHT

**3) Porosity p**

$F = \frac{R_o}{R_w} = \frac{2}{0.12} = 16.5$ approx.

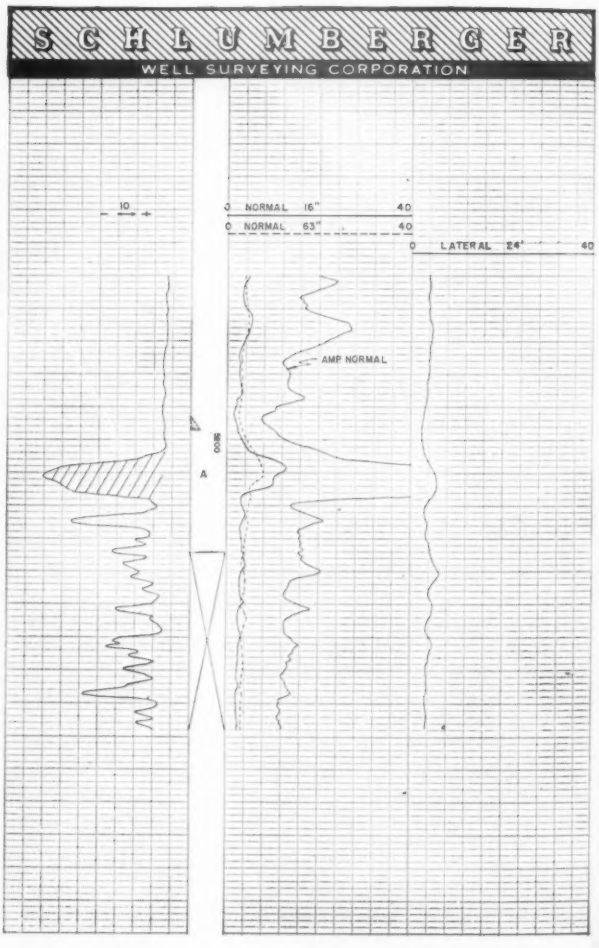
$p = \sqrt[m]{\frac{1}{F}} = 17\%$ for m = 1.6

## CORE ANALYSIS

| | |
|---|---|
| Average Porosity | 18% |
| Permeability: Average | 15 md. |
| Maximum | 113 md. |
| Residual Oil | 14% |

## PRODUCTION RESULTS

| | |
|---|---|
| Casing at: | 5193' |
| Plug Back: | 5234' |
| Production Potential: | 140 bbl. oil 39° API<br>26.5 MCF gas<br>Gas-oil ratio 189/1 |




SCHLUMBERGER
WELL SURVEYING CORP.
HOUSTON, TEXAS

# Guest Editorial

by

H. H. KAVELER, Member AIME

Assistant to Vice President

Phillips Petroleum Co.

Bartlesville, Oklahoma

# *MORE BANAUSIA*

THE meeting came to a sudden end.

A few lingered to hold a post-mortem discussion. They were mainly those who had come with high hopes that the session would lead to joint action toward instituting gas-injection pressure-maintenance in a recently developed pool. The objective of the meeting was to arrive at a distribution of equities in a proposed unit and adoption of a plan for secondary recovery operations. Those who lingered were operators who had engaged in unitized pressure-maintenance operations on many other occasions with high success and with credit to their good business judgment. Their hope was based on results of past experience, and, in addition, on the fact that gas wastage in the field in question was in itself a compelling reason to engage in a cooperative effort.

The meeting went well in its opening minutes. The majority present recognized the wasteful conditions existing, thought the pool should be unitized and appeared ready to accept the proposal to return the produced gas to the reservoir. Most agreed that details required to reach this objective could be worked out as they were encountered. But then the lightning struck.

APPARENTLY the word "detail" was the key that unlocked the storm. There were apparently some details that were overwhelmingly important. Someone arose to announce that the material balance principle had been utilized to predict the future behavior of the pool, and the calculations placed some question on the present worth of the increased future ultimate recovery as compared to the present worth of the recovery that might be obtained through ordinary pressure depletion. Then another held forth at some length on the fact that he, too, had utilized the material balance principle with the benefit of some particularly valuable $k_g$-$k_o$ data that were not heretofore available to the industry. His calculations produced some numerical variation from the conclusions of the previous speaker about the dollar value of the increased recovery. Then another discoursed on the result of his restored state experiments on rock of somewhat similar characteristics and introduced some uncertainties concerning the correctness of the reserve estimates of all who had previously spoken. And finally, there was a presentation on the part of one who had made a very detailed interpretation of core analyses. This speaker offered some rather dire predictions concerning the prospect for successful gas-injection pressure-maintenance based upon a lithological examination of the rock from the core of one well in the field.

With such diversity of conclusion in respect to the soundness of the idea of pressure maintenance, coupled with the obvious difficulties always incident to evaluating the separate properties overlying the common source of supply, it was now apparent that there could be no prospect of agreement on unitization.

And so the meeting ended.

THE technologists had produced a great show. Experts had disagreed with experts. Even the most ardent conservationist was shocked by the exposé. Few realized how grossly ignorant were those of the industry who in years past went forward with successful unitized secondary recovery operations without the benefit of all the new scientific tools. The old-timers wondered how they could have been fortunate to stumble along in such ignorance. It did appear that from this time on a forest of scientific deductions, requiring years to ferret, must be traversed before business men could approach the question of conservation in any particular reservoir. The scientific

method in hands of equally competent engineers had produced a diversity of "answers". In the disagreement over numerical conclusions, it was impossible for the owners of the pool to do what at first seemed an obvious necessity.

Those who remained at the post-mortem discussion had at a later date the opportunity to read Reese H. Taylor's article appearing in the March, 1949, issue of PETROLEUM TECHNOLOGY. In that article Taylor dealt with an equivalent situation and suggested that the circumstance was best described by what may be generally adopted as a useful word, "banausia". "The Greeks had a word for it" and it might be well for the petroleum engineering profession to adopt the word for its own guidance and benefit.

Engineers have clamored for an opportunity to have a voice in business management. Their presence in increasing numbers in the petroleum industry indicates that they are being afforded that opportunity. Whether they add or subtract from what is accomplished will depend in large measure upon whether or not they understand and appreciate the point of view which Reese Taylor has expressed. His viewpoint deserves wide and serious consideration.

The fortunate circumstance seldom exists where business conferences are attended by the required number of principals representing "one-over-banausia". They are those, as defined by Hans Suter in his reply to Taylor published in the July issue of PETROLEUM TECHNOLOGY, who through training or experience are capable of assaying the purely technical conclusions of banusians in determining the course that good business judgment would dictate. Until the time may come when the pseudo-precise conclusions of banausic technologists are properly weighed and proportioned, many worthwhile projects in the petroleum industry will continue to fall victim to uncertain answers derived from precise computations based upon faulty premises. Must an advancing world wait while a set of differential equations are solved to determine whether a ready-made answer exists? In a majority of instances the petroleum industry must go forward on the basis of broad concepts rather than on terms of stated engineering recipes.

SOMEWHERE along the line too many technologists have lost sight of the significance of "answers" to practical problems that cannot be stated in a formal textbook manner and, therefore, do not lend themselves to formal solution. Their training in the theory of measurement was not productive of a proper appreciation of the significance of answers. The "almighty" answer is too often regarded with a dignity that it does not deserve.

Hans Suter suggested a very useful metaphor in his reference to the choice of reliance upon celestial navigation or upon a bombsight when the problem is to reach a desired target. Most problems in the petroleum industry cannot be "pinpointed" as a target to be attacked by technologists. There is litle, if any, value in utilizing a banausic bombsight under circumstances where celestial navigation is the only sensible guide to the desired objective.

How often have opportunities to increase the value of a property from $4.00 to $4.95 been passed because some answer expertly derived by manipulations from premises that are in part faulty or imaginary has led some banausian to the conclusion that his principal should look forward to $5.00 instead of $4.95. It is at this point that business too often fails. Taylor has said, in essence, that successful business is directed toward objectives — not toward techniques; towards ends, and not means. His is timely advice of commanding importance.

Advice on how to succeed is not lacking. It is plentiful in the literature of the engineering profession. The recipe for practicing "The 'Engineering Method' ", is quoted on Page 28 of the November issue of PETROLEUM TECHNOLOGY, is unlikely to advance business or the engineering profession without a companion injection of anti-banausia serum to induce a point of view which Taylor has ably voiced.

IT IS time to inquire when technologists as a class are going to develop a greater measure of understanding of the relationship between purely technical conclusions and purely business aspects of a problem. This is not a matter of finding a *desired* answer to a business problem from engineering considerations, but is a question of properly weighing the uncertainties of an engineering conclusion in reaching a decision on a course of action. This inquiry might go particularly to those who practice the specialty of reservoir engineering. Their particular province is reserve estimates, prediction of future reservoir behavior, and conclusions in respect to the worth of properties. Certainly no field of the petroleum industry is of more interest to business management. If management had a means to precise answers in that field, then those who produced the answers would occupy a high place indeed. But who can produce those answers with certainty? Who, among the technologists, takes the time to warn management of the uncertainties of the conclusions presented in those particular fields? Is the answer appreciated in the light of the assumptions involved or the speculations introduced? Technologists have a responsibility to produce conclusions, but with it goes the responsibility of being certain the significance of the answer is understood. Engineering conclusion must be distinguished from wise choice of one or more courses of business action. Until the technologists appreciate their responsibility in assisting management in understanding the significance of a technical conclusion as it bears upon a choice of one of several courses of business action, too many business conferences will be held more on the order of a technical debating society. The result of continued argument over the correctness of individual answers will cause management to lose faith in the competence of technologists, and the engineering profession will suffer the loss of its recent gains in the counsels of business management. ★ ★ ★

## ALFONSO CARLOS BULNES

Died October 19, 1949, in Houston, after a short illness. He was born in Mexico City on September 24, 1909, and graduated at the California Institute of Technology and the University of California at Los Angeles.

His first assignment took him in 1934 to Mexico where he worked as a chemist in the Aguila refinery at Tampico. In 1938 he returned to the United States and joined the production department of Shell Oil Co., working in the production laboratory at Houston. In 1943 he was transferred to Midland as reservoir engineer, which position he held until his death.

He earned a well-deserved reputation for his studies in connection with the production characteristics of dolomitic limestone reservoirs, two important contributions to which were published in PETROLEUM TECHNOLOGY.

He was a member of the A.P.I., serving on the Topical Committee on Production Technology for the Southwestern District, and was also active in affairs of the Permian Basin Section of the AIME. ★ ★ ★

# W. E. Wrather to Receive 1950 Lucas Petroleum Medal

William E. Wrather, director of the U. S. Geological Survey, and 1948 president of the Institute has been designated by the Anthony F. Lucas Petroleum Medal Committee to receive the award of the Medal for 1950.

The Medal was established in 1936 as a memorial to the late Anthony F. Lucas and is to be awarded to recognize "distinguished achievement in improving the technique and practice of finding and producing petroleum."

The citation for the award of the medal to Wrather is:

> "For his untiring leadership in guiding and developing the science of petroleum geology, for reducing this science to effective application in practice, and for the inspiration he has given to others in the profession by his dedication to public service."

William Embry Wrather was born in Meade County, Kentucky. After his boyhood there he moved to Chicago to attend high school, where he first learned about geology and received the direction for his life's work. While attending the University of Chicago, he worked during the summers with the U. S. Geological Survey, where he increased his knowledge of the structure of rocks. While working toward a Ph. D. at Chicago the oil industry began developing rapidly, and before long our friend found himself on the Gulf coast as a scout for the Mellon interests. Geologists were about as new to the industry as the industry was new, but he worked steadily at structures and leases for the organization that finally became the Gulf Oil Co. Eventually he handed in his resignation and started on his own as a geologist in 1917, settling in Dallas. He gained steadily in reputation during the ensuing years, traveling all over the world.

In 1942 he went to Washington to assist the government in the procurement of mineral supplies outside of the United States. In 1943 then, he was appointed as director of the U. S. Geological Survey.

His membership in the AIME was started in 1915, and from that to his presidency in 1948 he has rendered many valuable services to the Institute. In addition he has long been active in the Geological Society of America and the A.A.P.G. ★ ★ ★

---

GLENN M. STEARNS has been appointed chief engineer of the Mid-Continent division of the British-American Oil Producing Co. With headquarters in Tulsa, he will be responsible for all engineering phases of the drilling and production operations of the company, and will supervise engineering personnel. He has had wide experience in engineering, in teaching and in production work. After graduating from Oklahoma University in P.E. he served in the field, then returned to the staff of the University, returned to the field, and in 1947 joined Sanolind Oil and Gas Co. where he has recently been serving as development superintendent. He has written several technical papers and many articles on engineering, and is now JOURNAL secretary for the Mid-Continent Local Section of AIME.

+

ROBERT G. HAMILTON has established the firm of Hamilton Well Log Consultants with headquarters in Tulsa to perform a specialized consulting service in electrical logging and well surveys. In addition to covering all phases of interpretation and evaluation of logs and surveys, the firm offers an educational service to companies desiring to educate company personnel in geology, production and engineering departments.

Hamilton recently resigned from Schlumberger Well Surveying Corp. after having been with that firm since 1935. He has extensive education and experience in the engineering and electrical logging fields.

+

CHARLES CRISS, in engineering work with Sohio Petroleum Co., has been transferred from the Michigan district to the reservoir engineering department in Oklahoma City.

# Recent Canadian Oil Developments

By J. D. Gustafson, Imperial Oil Limited, Calgary, Alberta

## Introduction

Although recent oil exploratory and development activity in Canada did not reach a really large scale until after the discovery of the Leduc Pool early in 1947, Canada has a long history as an oil producing nation. The earliest activity was at Oil Springs, Ontario, in the 1850's and ultimately some 18,000 wells were drilled for oil and gas in Ontario. The peak annual output from Ontario fields was reached in 1894 when production was nearly a million barrels, but Ontario's present production is down to about 200,000 barrels per year.

Probably the first event which drew the attention of oil men to Western Canada was a well drilled for water in 1885 at Medicine Hat, Alberta, which discovered natural gas. This led to the development of gas fields in the general area, shown in Fig. 1. The forerunner of the famous Turner Valley field in the foothills of southwestern Alberta was a distillate well which came in in 1914 near Black Diamond,[1] but active development of Turner Valley proper did not commence until 1924 when Madison limestone (Mississippian) production was discovered in Royalite No. 4. This well came in with a potential of 24,000,000 cubic feet of gas and yielded 500 to 600 barrels of distillate per day. Another of the early fields is Norman Wells near the Arctic Circle where Devonian limestone production was found in 1921.

Most of the recent development has been in the Central Alberta region and

J. D. Gustafson

all of the major finds have been in the Upper Devonian. No production of commercial significance has been found in formations older than Devonian and the youngest formations which are commercially productive are in the Cretaceous. The Viking sand at the base of the Upper Cretaceous is a wide spread gas producer and produces oil at Joseph Lake. The Lower Cretaceous produces oil in a number of pools such as Lloydminster, Vermilion and Whitemud and contains the tar sands which outcrop along the north part of the Athabasca River. In the foothills belt the most important discovery since Turner Valley is probably Pincher Creek near the International Boundary where Madison limestone distillate production is being developed.

The success in finding new fields in Western Canada during the past few years has led to intensified exploratory effort. At the end of September, 25 companies were reported to be engaged in geophysical exploration, with a total of 103 parties. Of the total, 78 were working in Alberta, 23 in Saskatchewan, and 2 in Manitoba. At the same time there were 40 to 45 rotaries engaged in wildcat drilling in Alberta and several in Saskatchewan and Manitoba.

## Geology

### General

Fig. 2 is a map showing the sedimentary areas of Canada. The Western Canada Basin where the sediments are thickest comprises only 15 per cent of the nation's land area, but contains roughly 800,000 square miles. It extends from the International Boundary northwestward 1,800 miles to the Arctic coast and from the Rocky Mountains on the west to the Precambrian shield on the east. The thickest accumulation of sedimentaries actually occurred in the region now occupied by the Rocky Mountains where total sedimentation may have been as much as 50,000 feet. In the eastern foothills where drilling has been carried to depths as great as 14,400 feet it is believed that the sedimentary accumulation is 18,000 to 20,000 feet. Naturally most of the development in the Western Canada Basin has been concentrated in the south part and it is this area which will be discussed in the following paragraphs.

The general surface geology of the south part of the basin is indicated in Fig. 3. The simple nature of the regional structure and the general stratigraphic column is also shown by a cross-section through the region. Paleozoic rocks outcrop on both sides of the basin. On the west they are intensely folded and faulted to form the Rocky Mountains. There is a gradual thickening of sediments from east to west with the beds dipping westward at the rate

Manuscript received at the office of the Petroleum Branch September 5, 1949. Paper presented at the Petroleum Branch meeting in Los Angeles, October 20-21.

[1]References given at end of the paper.

of a few feet per mile. Most of the surface bed rock in the basin is covered with glacial drift and the bed rock which is exposed is largely continental or brackish in character. Although much prospecting has been done and is being continued on an increasing scale, geological information is far from complete. Only 18 wells had penetrated into the Precambrian up to the first of October, 1949. There are a number of unconformities, one of which results in middle Devonian formations resting on the Cambrian throughout most of Alberta. Another major unconformity occurs between Paleozoic and Mesozoic. The Permian is absent throughout the basin and Lower Cretaceous overlies progressively older beds eastward.

General structure of the south part of the Western Canada Basin is illustrated by Fig. 4 which shows contours on the top of the Lower Cretaceous. In the south the principal features which extend into the United States are the Sweet Grass Arch and the Williston Basin. West of the Sweet Grass Arch the structure drops off rapidly into the old geosynclinal area. Extending northward from the Edmonton area is the Alberta homoclinal belt.

## Upper Devonian

Although Cretaceous, Jurassic, Triassic, and Mississippian possibilities are by no means overlooked in the current exploration in Western Canada, the Devonian receives most attention. Devonian stratigraphy and the character of Upper Devonian coral reefs in the area have been ably described by a number of authors[1,2,3] and will be reviewed only briefly here. Fig. 5 shows the extent of the Devonian outcrops in Canada and indicates the locations of the most important Upper Devonian pools. Leduc-Woodbend, Redwater, Golden Spike, and Stettler are undergoing development. Normandville, some 350 miles northwest of Edmonton, was discovered in September of this year and further development has not yet commenced. Princess, where the reservoir rock is fragmental dolomite, is not a reef type reservoir and this may be true of the producing zone at Normandville. At Leduc-Woodbend and Stettler the producing reefs are predominantly dolomite while the others are limestone.

Lithologic units of the Upper Devonian in Western Canada were first named after detailed study of the stratigraphy at Leduc. The Leduc terminology is now used throughout the basin and a description of the section there will illustrate the type of bioherm found in the Upper Devonian of Western Canada. Fig. 6 shows the Upper Devonian section penetrated in a typical Leduc-Woodbend well. At the top the D-1 Zone is overlain unconformably by Lower Cretaceous. The D-1 varies in thickness from 220 to 460 feet at Leduc and is composed largely of dolomite and dolomitic limestone, with small amounts of secondary anhydrite and chert. Anhydrite varying in thickness from 80 to 190 feet occurs below the D-1 Zone and underlying the anhydrite is the Red Bed Zone 30 to 40 feet thick. This is a mottled red and green silt stone with a high percentage of very fine quartz grains which are embedded in red and green argillaceous material. Underlying the Red Bed is the D-2 Zone which varies in thickness from 145 to 165 feet. This is the higher of the two main producing zones at Leduc. In the upper part it consists of finely crystalline dolomite with anhydrite-filled vugs. The oil pay is the middle part of the zone which is made up of a dolomitized limestone with crystalline and vuggy porosity. Fig. 7a is a photograph of a section of diamond core from the D-2 Zone to illustrate this type of porosity. Below the pay the dolomite is finely crystalline and becomes argillaceous

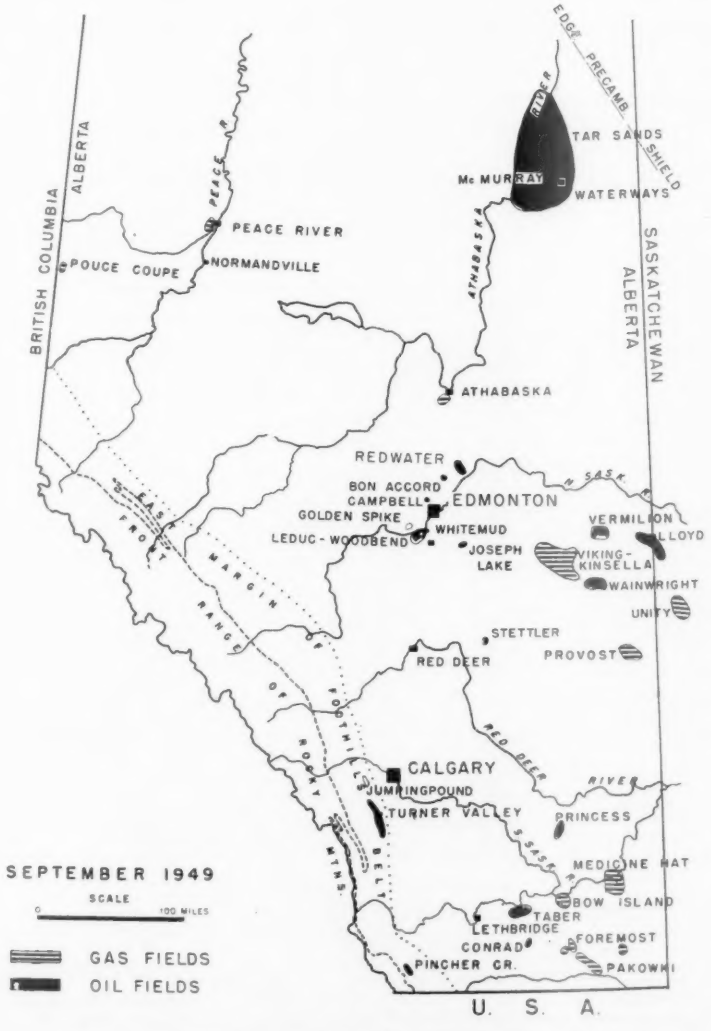



Fig. 1 — Alberta Oil and Gas Fields, September, 1949

with depth. The Green Shale Zone between the D-2 and the D-3 below varies from 125 to 225 feet in thickness over the producing area but becomes much thicker to the east. Approximately the top 20 feet of the D-3 reef is a zone of detrital material. The true bioherm below is fractured crystalline dolomite containing many vugs. Fig. 7b is a photograph of a diamond core section from the D-3 Zone showing the large vugs and the lack of bedding typical of this reservoir. The total thickness of the D-3 reef is approximately 700 feet.

Fig. 8 is a northeast-southwest cross-section through the Lower Cretaceous and Upper Devonian at Leduc-Woodbend. Regional dip in the Devonian is at a considerably higher rate than in the Cretaceous, and the degree of arching of the beds becomes progressively greater with depth. Closure on the D-3 reef is depositional in origin, while the arching above is believed to be a result of differential compaction during late Devonian time and perhaps subsequent tectonic action. This illustration shows the steep dip on the flanks of the D-3 reef and the pronounced thickening of the green shale, which forms a stratigraphic trap. The D-2 Zone is thought to be a shoal reef with porosity pinch-outs accounting for the oil accumulation.

### Development and Production

As shown in Fig. 9 there are now about 45 rigs engaged in development drilling in Alberta and most of these are located in the larger Devonian pools. As at October 1 there were approximately 1,085 producing wells in the Province and over 80 per cent of these were in fields which produced high gravity crude. The current market demand for Alberta's light crude is in the neighborhood of 60,000 barrels per day. Heavy crude production in Alberta and Saskatchewan during the summer and early fall amounted to some 7,000 barrels daily. By May of this year development of the new fields had proceeded to the point where potential as determined according to Alberta Conservation Board allowables equalled market demand. Since then the developed potential has outpaced producing rate. Total reservoir MER for the light crude pools discovered to date is probably well over twice current market demand. The sharp increase this year in number of rigs operating and in producing wells and potential is mainly due to development at Redwater which is believed to be the largest discovery in Canada to date. Table I presents a

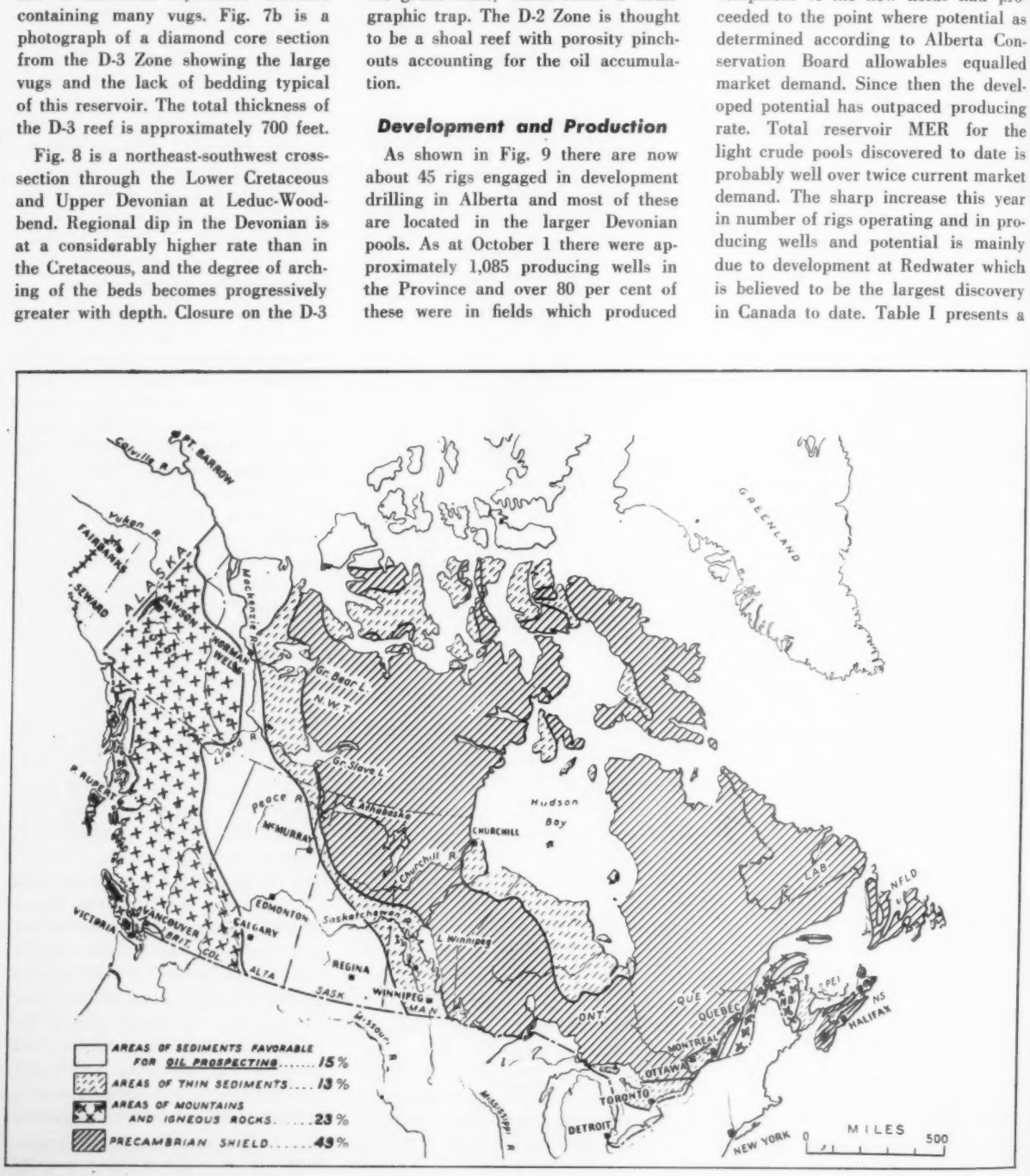



Fig. 2 — Sedimentary Areas of Canada.

summary of the development and production status of light crude pools.

No large increase in actual crude output from Western Canada fields is anticipated until completion of a pipe line from Edmonton southeast to Regina and thence to the head of the Lakes at Superior, Wisconsin. The line will be about 1,150 miles long and its initial capacity is to be 70,000 barrels per day. From Superior the crude will be shipped by lake tanker to refineries in southwestern Ontario. Storage capacity in excess of one million barrels is to be built at the Superior terminal to permit accumulation of crude during the five-month season when the lakes are closed. Completion of the project is scheduled for the spring of 1951.

### Drilling Conditions

Drilling depths in pool development range from less than 2,000 feet in the Cretaceous sand pools of Western Alberta and Eastern Saskatchewan to over 12,000 feet for Madison limestone production in the foothills. In Devonian pools the range is from 1,800 feet at Norman Wells to 6,700 feet at Normandville. Average depth at Redwater is 3,250 feet and at Leduc 5,250 feet. The majority of rigs in use are mechanical with diesel power, and drilling is done with rock bits. Most of the drilling rigs are owned and operated by independent contractors. Operations are retarded somewhat in the winter by low temperature and occasional heavy snow falls but not to the point of complete standstill. An auxiliary steam boiler to supply heat is a requisite during winter.

Drilling conditions in Western Canada are not unusually difficult. In the foothills the formations penetrated are extremely hard and steep dips and faults create straight hole problems but these are overcome by ordinary techniques. In the Central Alberta Plains the chief problem is that of lost circulation and blowout danger which is faced in drilling into fractured vuggy zones of the Devonian. The nature of the problem is illustrated in Fig. 10 which shows the typical geological section at Leduc. Gas is encountered in sands in the Belly River group, in the Viking Zone, and in Lower Cretaceous sands as well as in the D-1 Zone of the Devonian and in the top of the D-3. The D-3 Zone is extremely vuggy and apparently cavernous in some areas so that even when drilling mud characteristics are carefully controlled circulation is sometimes lost in drilling in this zone. This permits the gas zones higher up to blow out, the same conditions which precipitated the famous blowout of Atlantic No. 3. It has not been possible to prevent occasional loss of circulation when drilling into the D-3 and similar horizons but a casing program is now used which practically eliminates the blowout danger. For a D-3 well at Leduc, 10¾-inch surface pipe is set below the glacial drift, usually at a depth of 300 feet, and a 9-inch hole is then carried to the base of the green shale just above the pay. At this depth a 7-inch long string is cemented in the hole and the D-3 Zone is then drilled through the 7-inch. The well is usually completed through perforations in a 5-inch liner which is cemented from bottom hole through the D-3 gas cap and up into the 7-inch.

### Well Logging and Coring

In addition to drill cutting and core examination the most widely used form of logging in Western Canada is the usual electric log of self-potential and resistivity characteristics. In recent months Gamma ray and neutron log services have become available and are finding use for limestone formation logging. Probably the most valuable single tool for logging the vuggy fractured zones of the Devonian biotherms is the diamond core barrel. Core recovery in excess of 95 per cent is now usually achieved with the diamond barrel. Some difficulty is experienced in coring zones which tend to take drilling fluid, but the technique and the tools have been improved to the point where loss of circulation does not prohibit coring. Diamond core head performance has been improved by increasing the hardness of the matrix and enlarging water courses and in one company's experience average footage cored per bit has been increased from 225 to 450 feet during the past two years. Diamond coring costs now compare favorably with conventional methods.

### Well Completion Methods

Well completion methods in Devonian pools vary with the type of reservoir, and to some extent because of the usual differences among operators' preferences. The following generalizations will indicate how practices vary with reservoir conditions. In the relatively tight D-2 Zone at Leduc, where lost circulation is not a problem, open hole completions are made with casing set above the pay, after the hole has been drilled to total depth. Acidizing is practised as part of the completion usually only when necessary to cause the well to flow or to improve its flowing characteristics. Because the formation is predominantly dolomite, acidizing is not outstandingly successful in increasing initial potentials. It has yielded better results in wells which have been on production for six months or more. In the D-3 Zone at Leduc, where most completions are now made through perforated liners, acidizing is usually not considered necessary.

At Redwater where there is no gas

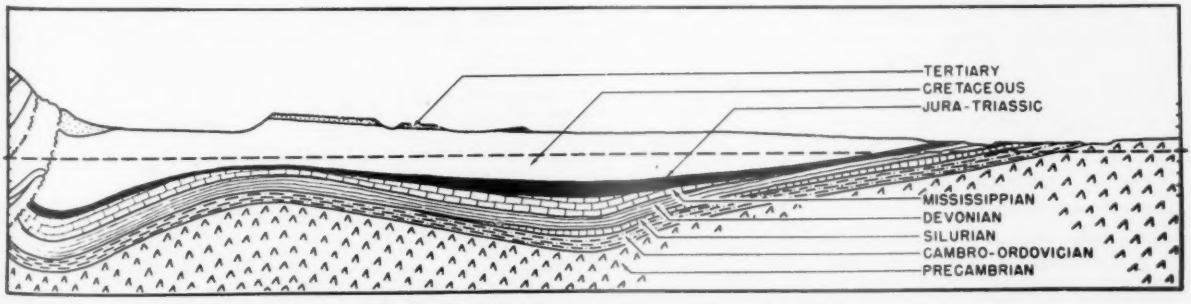



**Fig. 3 — Stratigraphic Cross Section Western Canadian Plains.**

cap to be shut off in the D-3 Zone most operators favor open hole completions unless the well is drilled below the water table for reservoir information. In this limestone reservoir acidizing is widely practiced, not so much for the purpose of increasing potential as to decrease the differential between reservoir shut-in pressure and flowing pressure. Because the formation takes acid on a surface vacuum a jet gun is used to provide better coverage of exposed formation in open hole completions and double packer acidizing tools are used to acidize through liners.

### Producing Conditions

In all of the new large Devonian pools in Alberta first production has been obtained by flowing but in many instances artificial lift will be necessary sooner or later during the producing life of a well. There is a good supply of hydroelectric power in Central Alberta and judging from installations which have been made by a number of operators thus far sucker rod pumping with electric power will be employed at fields such as Redwater and Leduc. Producing operations are not seriously hampered by cold weather if proper steps are taken to provide some form of heat at tank batteries. Common practice is to install a low pressure steam boiler at each tank battery and provide steam to thaw meters and lines and for heating stock tanks when necessary. One producing problem which faced operators early in the development of the new fields is that of emulsion treating. When Leduce wells began producing water in small amounts it was found that it would be necessary to dehydrate to very close specifications to provide crude acceptable to local refineries. This condition arises because of the very high salt content of water produced from the D-3 Zone. The emulsion treating problem is not difficult in the usual sense and by installing emulsion treaters and with the proper selection of treating chemicals and methods, deyhdration to very low water percentage is practical even in extremely cold weather.

Principal producing conditions and crude characteristics for some of the Alberta fields are summarized in Table II. It will be noted that most of the Devonian crude is relatively high in gravity. Paraffin formation in tubing and flow lines is something of a problem especially at Redwater but fortunately pour point of the crude is fairly low. The gas produced from the Madison limestone at Turner Valley and Pincher Creek is quite high in $H_2S$ content, while in the new Devonian pools only Redwater has sour gas.

### Reservoir Characteristics

The variation in reservoir conditions encountered in Western Canada is comparable in degree to the wide range of depths and formation types. At one extreme is the shallow Cretaceous sand production where pressures and gas-oil ratios are low and the crude is viscous,

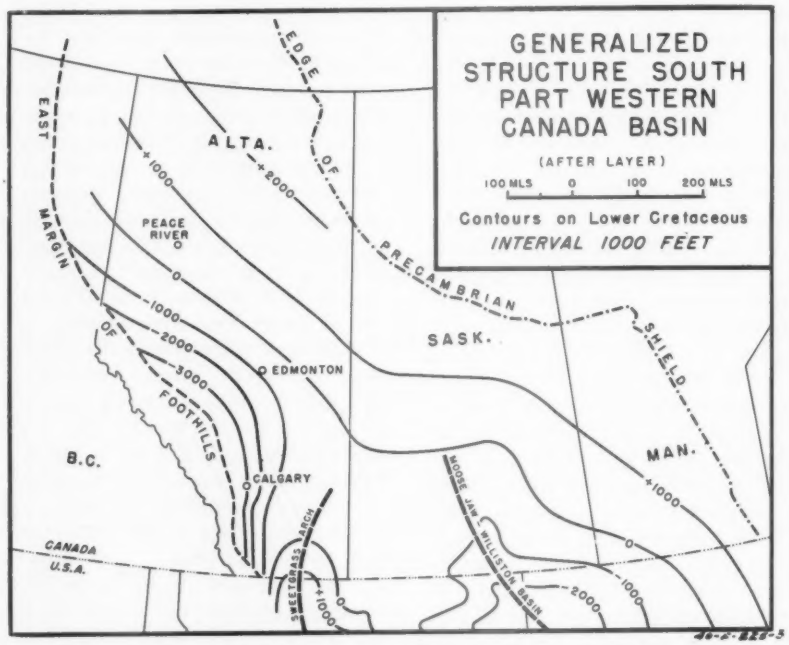



Fig. 4 — Generalized Structure South Part Western Canada Basin.

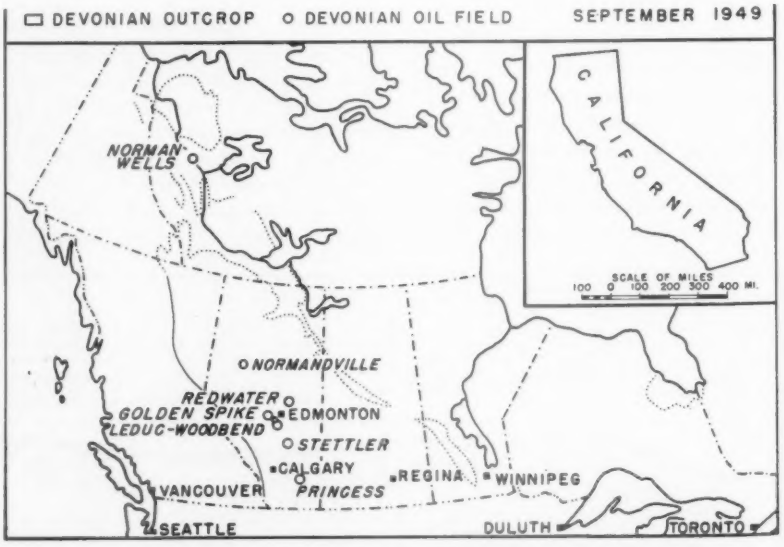



Fig. 5 — Western Canadian Basin Devonian Oil Fields.

## TABLE 1

*Alberta Light Crude Production*

*October 1, 1949*

| Pool | Producing Horizon | Approximate No. of Wells | Approximate Producing Rate Bbls/Day September 1949 |
|---|---|---|---|
| Leduc-Woodbend | D-2 & D-3 | 315 | 31,500 |
| Redwater | D-3 | 195 | 20,900 |
| Golden Spike | D-3 | 1 | 300 |
| Stettler | D-2 & D-3 | 1 | |
| Turner Valley | Madison | 307 | 10,400 |
| Others | | 61 | 1,600 |
| | | 880 | 64,700* |

*September production higher than normal demand because of harvesting season.

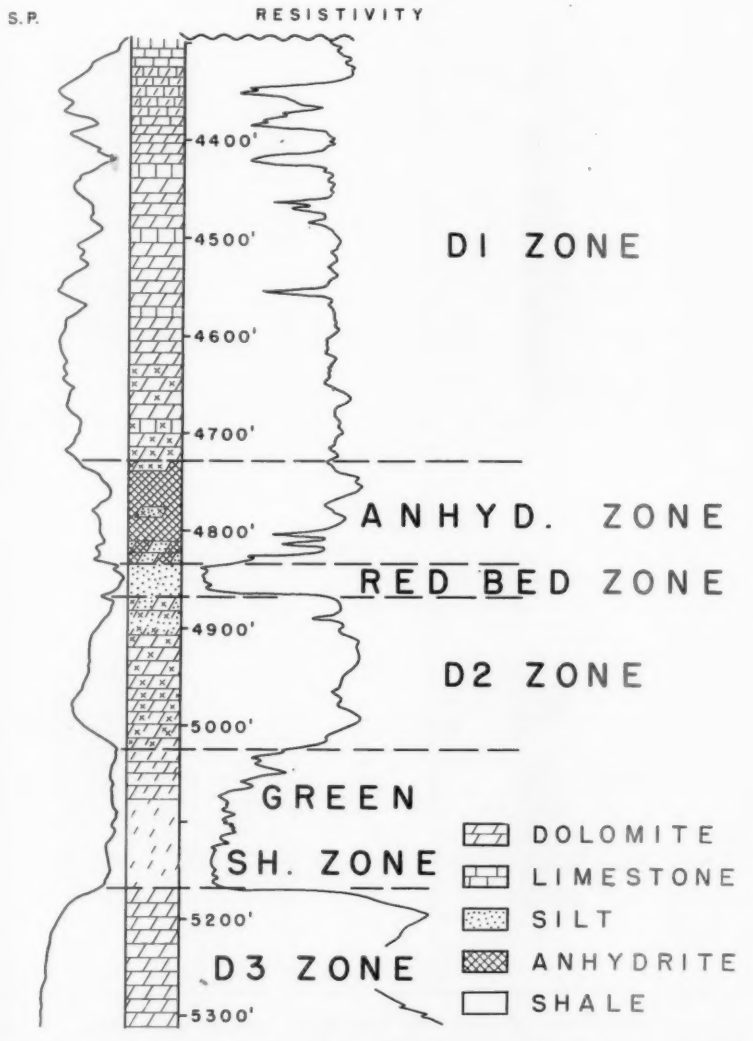



**Fig. 6—Devonian Section—Typical Leduc Well Showing Electric Log Anomalies.**

while at the other is the deep Madison limestone distillate production in the foothills with high reservoir pressures and temperatures (See Table II).

While most of the Upper Devonian reservoirs are of the same general type, each requires the usual individual analysis and study. The new fields, beginning with Leduc-Woodbend, do not yet have sufficient production history to permit thorough analysis of reservoir behavior but certain tentative conclusions can be drawn. The D-2 Zone reservoir at Leduc does not have a large uniform water body underlying the oil and there are only small and localized gas caps. Consequently, the primary recovery mechanism is expected to be solution gas drive. The D-3 Zone has a large gas cap, approximately 1.3 times the oil saturated section in volume, and there is some 600 feet of water zone underlying and connected with the oil pay. Gas cap expansion is expected to be the primary recovery mechanism but water drive action might also have an important role in depleting the reservoir. At Redwater there is no gas cap and the D-3 Zone crude is under-saturated. There is approximately 1,000 feet of porous water-bearing formation underlying the oil and apparently the oil and water zones are well connected. It is too early to predict whether the size of the aquifer in relation to the volume of the oil pay is such as to permit a fully effective natural water drive, but the low pressure decline rate to date indicates that water influx is taking place.

One of the principal problems of the geologists and reservoir engineers in dealing with the reef reservoirs is to evaluate the distribution of porosity between the intergranular type and the porosity made up of vugs and fractures. The problem was first attacked through sample examination and by visual measurements of core surfaces but analytical techniques are being developed utilizing the large diamond cores. An Imperial project using an adaptation of the Purcell method with large cores is now showing considerable promise of yielding an accurate quantitative expression of pore size distribution at very reasonable cost. A paper on this work may be published in the new year.

Porosity and permeability are being measured on the large diameter dia-

mond core samples with what are believed to be more accurate results than those obtained from the usual small core plugs. This work is important not only to reserves estimating and reservoir analysis generally but to the planning of producing methods and secondary recovery programs. An indication of the magnitude of porosity and permeability found in the Devonian reefs may be had from the following tentative data. The dolomitic D-2 Zone at Leduc-Woodbend has an average effective porosity of about 10 per cent and permeability of 25 millidarcies. The reef dolomite in the D-3 Zone has an effective porosity averaging approximately 13 per cent and permeability of 300 millidarcies. Effective porosity in the D-3 limestone at Redwater is currently placed at 10 per cent and permability at 800 millidarcies.

### General Operating Conditions

Oil field operations in Western Canada are more nearly similar to those in United States fields than to "foreign" operations as typified for example by South America or the Middle East. Although the Crown or Provincial Government is by far the largest mineral owner in Alberta and grants prospecting rights on large blocks of acreage there is a fair sprinkling of freehold leases in many areas of the Province. Competition among operators is also encouraged by the Government's policy of offering proven or semi-proven "Crown reserves" for sale by sealed bidding. When a discovery is made on an exploratory "reservation", the size of the lease which the operator may acquire for development purposes is restricted and the Government may then, from time to time, sell parcels of its Crown reserves. This policy tends to increase the number of operators in a pool. There are now in the neighborhood of 120 operators actively engaged in exploration and development in Western Canada. A majority of the United States firms which are usually classed as the major companies are represented through Canadian subsidiaries while independents are made up of both United States and Canadian operators with the latter being in the majority.

There is no lack of the usual oil field specialized services including all types of well logging, acidizing, cementing, gun perforating, and laboratory facili-

TABLE II

*Producing Conditions and Crude Characteristics Five Alberta Oil Pools*

| Pool | Pincher Creek | Redwater | Leduc | Leduc | Whitemud | Lloydminster |
|---|---|---|---|---|---|---|
| Formation | Madison Limestone | Devonian D-3 | Devonian D-3 | Devonian D-2 | Lower Cret. Ss. | Lower Cret. Ss. |
| Depth, Feet | 12,000 | 3,250 | 5,350 | 5,150 | 4,050 | 1,900 |
| Original B.H. Press., p.s.i. | 4,855 | 1,050 | 1,894 | 1,760 | 1,300 | 500 |
| Reservoir Temperature, °F. | 184 | 94 | 152 | 149 | 124 | 72 |
| Initial Potential Range Bbl/Day | 648* | 600–3300 | 100–3400 | 100–2500 | 200–650 | 10–500 |
| Solution GOR, Cu. Ft./Bbl (Flash Liberation) | 21,000 | 215 | 733 | 680 | 436 | Very Low |
| Saturation Pressure p.s.i.g. | | 485 | 1,894 | 1,760 | 1,300 | ? |
| Crude Base | Condensate | Paraffin | Paraffin | Paraffin | Intermediate | Asphalt |
| Crude Gravity, °A.P.I. | 53 | 35 | 41 | 40 | 36.5 | 14 |
| H2S Content | 15% | 4–5% | Nil | Trace | Nil | 3% |
| Pour Point of Crude, °F. | ? | —15 | — 5 | —10 | ? | 10 |

*Open flow 22,000 to 80,000 Mcf./Day 2 wells)

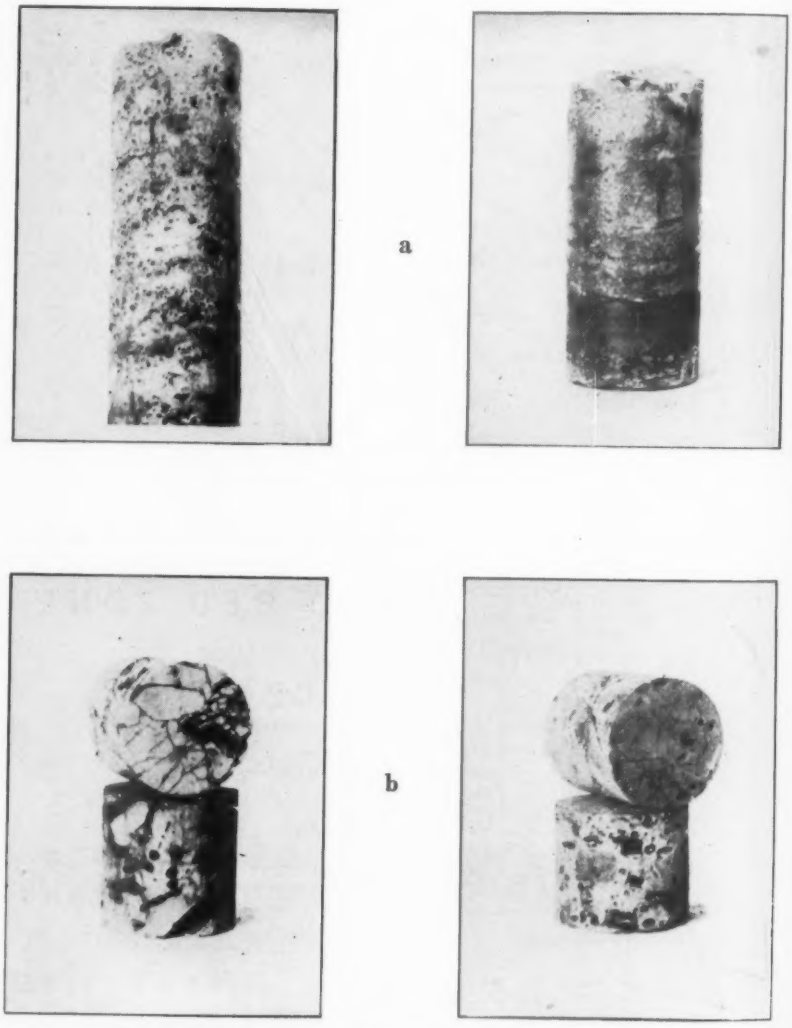



Fig. 7 — a. Devonian D-2 Zone Core Samples, Leduc Pool.
b. Devonian D-3 Zone Core Samples, Leduc Pool.

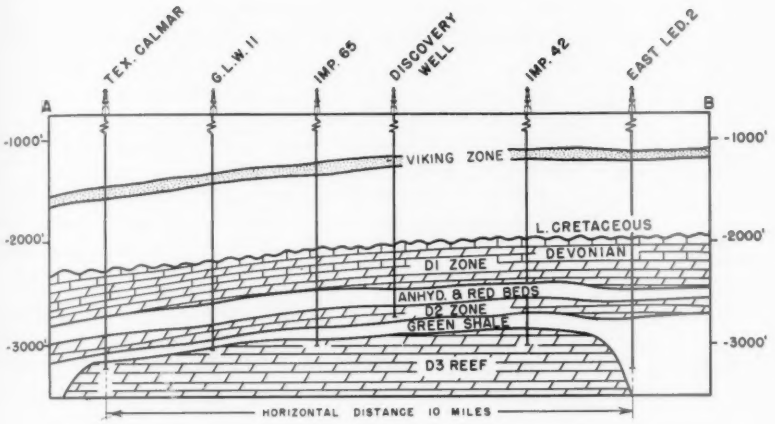



**Fig. 8 — N.E.-S.W. Section Across the Leduc Field, Vertical Scale Exaggerated 20 Times (After Layer).**

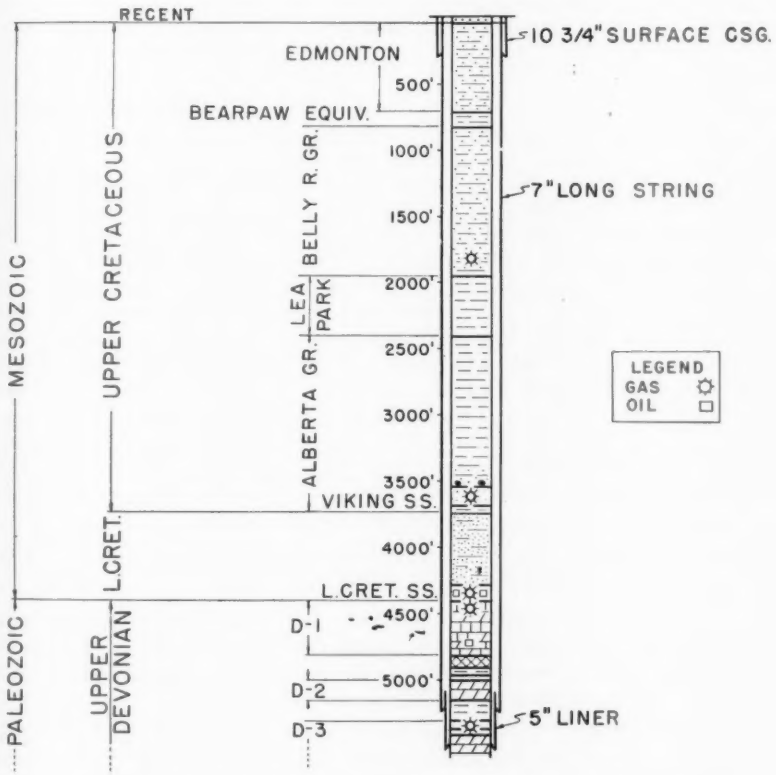



**Fig. 10 — Leduc Geological Section Showing Casing Program for D-3 Zone.**

ties. Equipment supply store stocks were somewhat limited up to two years ago but the supply situation with respect both to competition and stocks now compares with most major oil producing areas in the United States. So far all of the seamless tubular goods used in Canada comes from the United States mills but much of the line pipe and an increasing proportion of tank and separator steel is of Canadian manufacture. No import duty is collected on

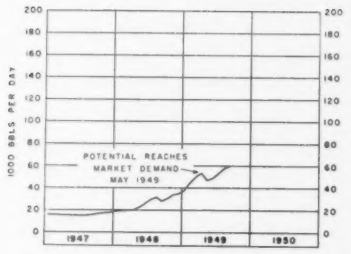
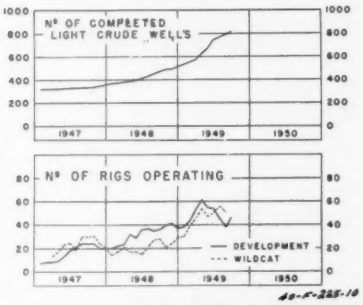



**Fig. 9—a. Alberta light crude production.**




**b. Rate of Development, Alberta, Canada.**

most of the material used in drilling and equipping oil and gas wells.

### Acknowledgment

The writer wishes to express his thanks to Imperial Oil Limited for permission to publish this paper.

Grateful acknowledgment is made for the assistance of D. B. Layer and other members of the Geological staff, and E. D. Wilson and staff of the Petroleum Engineering Department, Imperial Oil Limited, Producing Department, Western Division, in preparation of the geological material and development statistics.

### References

1. Layer, D. B. et al, "Leduc Oil Field Alberta, Devonian Coral Reef Discovery". *Bulletin* of American Association of Petroleum Geologists, Vol. 33, No. 4, July, 1949.
2. Link, Dr. T. A., "Leduc Oil Field Alberta, Canada, An Example of Transgressive and Regressive Bioherm Growths". *Bulletin* of the Geological Society of America, Vol. 60, March, 1949.
3. Waring and Layer, "A Devonian Dolomitized Reef". Paper presented at Annual Meeting of American Association of Petroleum Geologists, St. Louis, Missouri, March 16, 1949.

★ ★ ★

# *OPEN MEETING OF THE EXECUTIVE COMMITTEE*

# *PETROLEUM BRANCH, AIME*

*San Antonio, Texas, October 5, 1949*

CHAIRMAN ELKINS: The minutes of the Executive Committee meeting in San Francisco were published in the JOURNAL. If there are no questions, we will consider them approved.

The second item on the program is the announcement of the Publications Committee and the Production Review Committee chairmen for 1950. They are: Owen F. Thornton, The Texas Co., Chairman of the Publications Committee; and D. V. Carter, Magnolia Pet. Co., Chairman of the Production Review Committee. The members of the Publications Committee are: J. M. Bugbee, Shell Oil Co., Houston, Vice-Chairman; R. C. Craze, Humble Oil & Ref. Co., Houston; Eldon N. Dunlap, California Research Corp., New Orleans; D. L. Marshall, DeGolyer and MacNaughton, Dallas, and J. L. Hoyt, Pan American Prod. Co., Houston.

We will now have a report from the Chairman of our 1949 Publications Committee, Gordon Fisher.

### *Publications Committee Report*

G. H. FISHER: The Committee had on hand at the time its year began, 32 papers, none of which had been cleared for publication. In the year prior to October 1, 1949, 47 additional papers were considered, while 34 others are anticipated as a result of the fall meetings. This makes a total of 113 papers considered to have been in the hands of the Committee this year. Thirty-five papers have been published in the JOURNAL as Technical Papers and 14 as "Articles," while 14 papers have been rejected. At this time, 3 Technical Papers and 1 "Article" are approved, with publication pending.

The Committee this year was operating under a greater publications demand than had existed in the past, by reason of the monthly issuance of the JOURNAL. I would like to urge the entire membership of the Petroleum Branch that when selected as readers they return their opinions promptly so that delay in deciding upon the papers will be minimized.

It is recommended that the practice followed this year with reference to "Articles" for the JOURNAL be continued, in order that the papers which in many cases are impaired in value if several months' delay is occasioned, may be published shortly after their receipt. It likewise is recommended that a revision be made with regard to relations between the Main Publications Committee in New York and the Auxiliary Publications Committee of the Petroleum Branch. It is my feeling that Technical Papers for the JOURNAL should not require approval from New York, and likewise that notices of rejection should be sent by the Petroleum Branch Committee without reference to New York. These statements are made after careful and deliberate consideration of the operation of the Branch Publications Committee during the past year.

In closing, I should like to express my gratitude for the cooperation of the Committee members and W. H. Strang.

CHAIRMAN ELKINS: Thank you, Gordon. Everyone who thinks about the problem Gordon and his committee had this year in gearing up for the JOURNAL realizes that they have done an excellent job.

I believe we should add emphasis to the problem of obtaining prompt reader comment. I know how easy it is for a reader to stick the paper in his basket and forget it for a week or two. That hampers the Committee; they're trying to get the magazine out. Our relationship with the Publications Committee of the AIME in New York deserves discussing. The matter was discussed with the Board last year and it was recognized that the Petroleum Branch was different from the other Branches. The Board was inclined to give almost full authority to our Publications Committee. However, this year such a relationship has never fully developed. I believe the Board would still be agreeable to delegating much more responsibility to our Publications Committee.

We are very happy to have with us Mr. Robie, who is our Secretary in New York. I want him to feel free to make any comments that he wants to.

*There followed a discussion joined in by the Chairman and S. E. Buckley, C. V. Millikan, E. H. Robie, G. F. Moulton, G. H. Fisher, V. H. Decker, J. H. Murrell, P. Andrews and I. W. Alcorn which involved, in too much detail for general interest, the past and possible future definition of Branch Publications Committee authority. It was concluded by the following motion:*

J. H. MURRELL: I move that the past and present chairmen of the Branch Publications Committee get together with the Chairman of the New York Committee and work out a satisfactory procedure in line with Institute policy.

S. E. BUCKLEY: I wish to amend the motion to include the instruction that our Committee chairmen, prior to discussion with the New York Committee, draft a set of working rules to serve as a basis for discussion.

Motion and amendment were carried.

CHAIRMAN ELKINS: The next topic is a report from the 1949 Membership Committee. The Secretary will represent F. H. Briggs, the Committee Chairman.

### Membership Committee Report

W. H. STRANG: The principal activity to date has been a postcard canvass in which all members in the U. S. were asked to submit to us the names of one or more non-members. Over 600 people have helped to the extent of 1,021 names. We have sent these prospects two complimentary copies of the JOURNAL. To the first copy we attached a sheet explaining that this complimentary subscription was to give them background on the AIME, and telling them that we would give them information on the nearest AIME local organization by other means. The prospect list has been broken down by F. H. Briggs to his regional Membership Committee representatives and for the most part, I believe, they are now in the process of extending personal invitations to these people to apply for AIME membership, supplementing this by invitations to Local Section meetings.

The cost of mailing these 1,021 copies of each of two issues of the JOURNAL has been borne by the Special Projects Fund; that is, it is not taken out of Institute operating revenue. The total cost has been about $250.

It is too early to tell exactly what the results of such a membership procedure will be, but already there are indications of success. Regardless of results over the next several months, I believe that the flow of new members next year and the following year may in some part be attributed to the fact that this year we gave these prospects a clearer conception of the AIME than they might have had otherwise. I don't think that we can ever totally evaluate this new member solicitation process, but I do think that even with the results that we can definitely fix, we will find it a successful method of attracting new members.

Figures for five months, April to August, indicate 138 new members for the Mining Branch, 124 for the Petroleum Branch, and 72 for the Metals Branch. The Petroleum Branch is only numerically 25 per cent of the Institute strength, so these figures indicate that, as in the past several years, we are gaining strength much more rapidly than the other two Branches. You can make various projects of the trend of membership growth but from the best figures available, it appears that in about, let's say, five to ten years the Petroleum Branch will be the largest in the Institute.

E. H. ROBIE: I think most of that advance has been due to the excellent work the Dallas office has been doing.

W. H. STRANG: Thank you. I think the principal factor has been our very excellent membership committees. For example, Terry Pollard last year did a lot of work. He applied himself to the task as well as any man possibly could and got good support from his committee throughout.

CHAIRMAN ELKINS: On the basis of the report that the Membership Committee put out for the first eight months of this year, we had 454 new members which, of course, includes some transfers. That is 35 per cent of the total new members of the same type for the entire Institute.

### Changes in Statistics Volume

Let us proceed to the next topic; the discussion of the proposed changes in the Statistics Volume. As background for that topic, I will mention that at present it costs us about $12,000 to put out the Statistics Volume. That is financed to the extent of $5,000 by the Doherty Fund provided by the Cities Service Oil Co., and we therefore have to look to other sources for the $7,000.

J. H. MURRELL: It cost that much more last year, but it's not going to cost that much more this year, is it?

W. H. STRANG: That much, less probably $800 saved by a revised method of proofreading.

CHAIRMAN ELKINS: Your Executive Committee is trying to make every function of our organization self-supporting, and in doing so we have considered several ways and means of getting the same information to our membership for less money. We have made the pledge to you that in three years we hope to be able to bring about a reduction in dues. Two years more will tell.

The Secretary has a report that has been forwarded to the Executive Committee which I would like to have him summarize at this time, regarding a proposal which we have for handling this next year's problem.

W. H. STRANG: The proposal is this: That we change the forms and instructions sent to authors of the statistical reports so that when copy is received from these authors it is fit for reproduction immediately by the lithographic process; and that these reports as they come in from February through September be carried as a separate section of the JOURNAL. The reports can be printed as rapidly as they come in. There will be only minor delays because there is no question of proofreading in offset lithography.

This plan eliminates the cost of hard binding, and because offset lithography is so markedly cheaper than linotype composition, indications are that we can circulate those statistical reports for a figure about, or possibly under, the amount of the Doherty contribution. This system has the added advantage of getting the reports out as they come in. The statistical authors' works — and those compilations are really tedious

things — will be brought to the attention of far more people than now see them.

Another advantage is the strength which this would add to the JOURNAL and what it might mean in a few years in terms of more advertising revenue. Certainly these statistics have a lot of popularity and strength that is not now benefiting the JOURNAL.

There are disadvantages. The authors would be limited in the form in which they prepared the tabular material. Unique conditions in certain areas couldn't be treated exactly as the author might want to treat them, because of the rigid limitations imposed by the mechanics of offset lithography. The appearance of the printed sheets would not compare with those in the other sections of the JOURNAL.

There is an alternative step open to us, in that if it is decided to put the Statistical Section in the JOURNAL, it would then be worthwhile to investigate Varityping, which means that the copy would be received from the author in usual forms, transcribed by Varitype process and then reproduced by offset lithography. In the transcription by Varitype everything could be made neat and you would have some flexibility in transposing the copy as the author put it down into something that would meet his wishes when it was finally printed. There again, you introduce the delay and the expense of proofreading and the delay and expense of Varitying.

J. H. MURRELL: Wasn't there something else — that these sheets could be saved and put together in a final volume for those who wished to pay for them?

W. H. STRANG: Yes. This section of the JOURNAL could be overrun and these accumulated monthly sections could be bound in November into a hardbound volume and furnished to those who wanted it at cost, which is estimated at $3.00. It should be mentioned that the new plan has this further disadvantage. As reports would be printed as they come in, neither their order of occurrence in the volume or the JOURNAL would be in a natural order.

J. H. MURRELL: That could be corrected in the bound book, couldn't it?

W. H. STRANG: When you print the magazine pages certain numbers are on them and it would be impossible to change the numbers on an offset plate. The book would be a stacking of the sections as they occurred in the magazine. We would furnish a Table of Contents which would enable anyone to readily locate any particular report.

H. F. BEARDMORE: Would the inclusion in the JOURNAL of the Statistics reports still attract the Doherty contribution?

W. H. STRANG: We are hopeful that it would. Mr. Lovejoy, I believe, knows about the proposal and there has been no indication that the contribution would be cut off if we changed the method of distribution. If that were to take place then we would have to abandon the whole plan.

S. E. BUCKLEY: What would be the additional cost if instead of just shooting them as they come in, you go through the auxiliary typing?

W. H. STRANG: I can't tell you accurately now. I had hoped that the Committee would decide today that publication in the JOURNAL was an appropriate means of circulating the statistical reports. I would then investigate the cost of Varityping and report. Certainly it would increase the cost $2,000.

B. C. CRAFT: From your experience, isn't it almost a certainty that it will be necessary to Varitype the reports? Don't those papers come in rather untidy and smeared? I remember when I had something to do with that, we got them in ink, typewritten, in pencil, and in all forms.

S. E. BUCKLEY: Using the original report would discredit the magazine.

W. H. STRANG: Our hope of being able to photograph the author's original report is based on a plan to revise the standard authors' forms so that they can be completed on a typewriter, and in addition to give the author stringent instructions on neatness, spacing, etc. It would be hard for the authors to comply with all of these mechanical requirements. That direct offset lithography could do the job at all is based entirely on the hope that we could get a terrific amount of conformance on very small details.

D. V. Carter of Texas, Gerald Eddy of Michigan, and Ray Larsen, of Wyoming, Production Review Committee members, have all indicated approval of the basic idea of circulating the statistical reports by means of the JOURNAL. They are all men who are familiar with problems from both the author's viewpoint and the committee viewpoint. D. V. Carter is of the impression that if the principal production and geological executives of the various larger companies were contacted, they might place with us standing orders for large quantities of copies for placement in all their district and division production and geological offices.

V. H. DECKER: I move that we accept the new method of publishing statistical volumes in the JOURNAL and that the details be left to the Secretary.

The motion was seconded and carried.

### *Illinois Basin Chapter*

CHAIRMAN ELKINS: We have a petition from a group centering in Mount Vernon, Illinois, operative for several years as the Illinois Society of Petroleum Engineers, asking permission to affiliate as the Illinois Basin Chapter of the Branch. Their by-laws have been submitted to the Executive Committee. One question has been raised, concerning the fact that there is no specific provision in these by-laws as to whether or not non-members of the AIME can vote on policy matters of the AIME. The by-laws set forth a provision that the officers of the Chapter will be Members of the AIME, but that the three members of the Board may be "local" members and not members of the AIME, provided that "Local Membership" is at least 15 per cent of the total membership of the Chapter. Whenever we give sanction to the conversion of an existing organization into an AIME group and provide for local members, there is always concern as to whether or not non-AIME members, numerous in the original organization, will get adequate representation. Conversely, they aren't supposed to vote on AIME matters except those of purely local significance. I have gone over this with Cecil Hamman who is here representing the Illinois Basin Chapter and recommend to the Executive Committee that we leave it to the officers of the new Chapter as to whether a sentence can be included in the by-laws that will clarify this matter. Even if they feel that

this should not be done I still recommend that we approve the petition just as it is, because I don't think the omission will ever cause any difficulties. As far as the Institute is concerned in the election of officers in the new Chapter, it is well protected.

B. C. CRAFT: Mr. Chairman, I move that the Executive Committee approve the petition and by-laws as submitted, and that a charter be granted to the Illinois Basin group.

The motion was seconded and carried.

CHAIRMAN ELKINS: For your information, we may have another chapter making petition for a charter in Casper, Wyoming, very shortly. Interest up there, and in Denver, is at a high level, and I think the leadership up there will develop it this fall.

T. C. FRICK: Mr. Chairman, in the Permian Basin we have a group in and near Lubbock, Texas, who have approached us about forming a Section at Lubbock. Because of the lack of members in numbers, I have not encouraged the formation of a complete new Section, but I do feel that something could be done up there. They point out that there are potentially 75 or 100 engineers in the locality who are not now members of the AIME. At the present time there are about 30 AIME members in the vicinity of Lubbock. It is my opinion that this is too small a group to form a very active Section, because there are actually only 12 of those residing in the town of Lubbock. If the Committee has no objection I believe I will make the suggestion to the Lubock group that they try the Sub Section idea for a year and see if they can increase their membership.

S. E. BUCKLEY: Do they really want to form a Section, or a Chapter of the Petroleum Branch?

T. C. FRICK: They want to form a separate Section.

S. E. BUCKLEY: If it's a Section they want, that's not this Branch's business, is it?

W. H. STRANG: That is correct, except possibly in an advisory capacity.

S. E. BUCKLEY: A Section is entirely distinct from a Chapter of the Petroleum Branch. A Section like the Gulf Coast or the Permian Basin is a part of the Institute as a whole, isn't it?

W. H. STRANG: You are perfectly right. The Branch is supposed to have no authority or responsibility as to the administration of Local Sections.

CHAIRMAN ELKINS: The expression of the Executive Com mittee, unless you correct me, is that we do not believe the Lubbock group is big enough to apply now for Section status, but that, under the Permian Basin, a Sub Section, or study group, or whatever you may wish to call it, with some identity and local organization, is perfectly in order.

E. N. DUNLAP: The Mississippi Sub Section has somewhere around 125 members.

CHAIRMAN ELKINS: Let me ask you a question. When you, as chairman of the Delta Section, get a check from New York, say, for $50 for 25 new members, what do you do with it? Do you keep it or do you send it up to your Sub Section if they happen to have the new members?

E. N. DUNLAP: Most of the recent new members have come from the New Orleans area and no allocation of the refund has been made; we plan to allocate the accumulated refunds on the basis of new members during the year.

CHAIRMAN ELKINS: My reason for asking that question was that we have the same problem Institute-wide with our Chapters, which do not have Section standing. I am going to try to work out with Mr. Robie a method on that. Sometimes a Petroleum Chapter which is within a geographic section contributes a lot of new members, but since they are not integrated with their Section, and are not, in some cases, even participating in the government of the Section, the initiation-fee rebate goes back to the Section and the Chapter may not get anything.

### *1950 Fall Meeting Site*

The next topic is confirmation of the 1950 easternmost fall meeting site. This is a matter for official action.

W. H. STRANG: The Committee will recall that at San Francisco Mr. Dunlap issued an invitation from the Delta Section to establish New Orleans as the site for one of our 1950 fall meetings. The Executive Committee at that time instructed that the facilities be investigated so that the decision to meet in New Orleans could be made final at this meeting.

The hotel facilities in New Orleans are adequate, the expense no greater than would be expected, or no greater than we are accustomed to in connection with these meetings, and the dates that we wanted have been granted us — October 4-6. I recommend that the Committee now confirm New Orleans as the site of the 1950 Petroleum Branch easternmost fall meeting.

CHAIRMAN ELKINS: What are the dates for the ASME meeting in New Orleans next year?

B. C. CRAFT: I believe it has been set for September 27 and 28.

G. F. MOULTON: I move that the fall meeting dates be approved as October 4-6, 1950, in New Orleans.

The motion was seconded and carried.

J. H. MURRELL: May I ask a question that I know will be very unpopular. Why do we move around to have our meetings? Why don't we set one central place and meet there every year?

S. E. BUCKLEY: Too many people don't like Dallas!

R. J. BETHANCOURT: If we didn't have these meetings you wouldn't have any place to go in your life!

J. H. MURRELL: That's a good answer.

### *Selection of AIME Directors*

CHAIRMAN ELKINS: We may get to the point where the hotel situation forces us to choose from two or three cities. The next item on the agenda is a report on the activities of the AIME committee studying revised methods of Director selection. Most of you recall that the Johnson Committee and a Committee on Democratization have continually held up before the Board of Directors the recommendation that it consider reorganization of the Board itself. It has been suggested that the Board be made smaller; that the Board have fewer meetings; and that these be spread geographically. There has

been a suggestion made that younger members be appointed to the Board.

The Board several months ago appointed a committee to clarify the instructions to the Nominating Committee, which always runs into difficulty when it comes to nominating the Directors. At the request of the Petroleum Branch, the Board was also asked to reconsider the methods of nominating the Directors.

Your chairman happens to be on the committee to which the Petroleum Branch proposal was handed for study and recommendation. I want to get any expressions in regard to Director selection that you might have.

Under the proposal that the Branch Executive Committee made, the number of Directors would be reduced very little. There are now 36 on the Board. There would be 31 ultimately under our proposal. Secondly, there would be three nominating groups: the Board of Directors would nominate the Vice-President and President; each of the Districts would have a certain allocated number of Directors and would nominate Directors to fill vacancies in their own Districts (the Nominating Committee in each District would be the Chairmen of Sections in that District, with the chairmanship of the Committee rotating between the Section Chairmen); and each of the Branches would be responsible for filling three Directorships, in addition to the Chairman of the Branch who is a member of the Board, ex-officio.

There are many who would like to see a Board of Directors numbering 12 or 15. There is argument on the other side, too. It's hard to get a meeting now of 12 or 15 with 36 on the Board; If you cut it down to 12 or 15 it would be all the harder. You probably couldn't get representation with a smaller Board. At least, with 30-35 members on the Board, they are all out and interested in things; they participate in action of the Board on items coming in through the mail, if not by actual presence. The group on Democratization thought a smaller Board would be better, but maybe it would not be better. Those are the viewpoints.

J. H. MURRELL: How often do you meet now?

CHAIRMAN ELKINS: The Board met this year about 10 or 11 times during a 12-month period — at least 10 times.

J. H. MURRELL: What's the reason for such a great number of meetings?

CHAIRMAN ELKINS: Mr. Robie might better answer that, but I think probably the reason this year was that the AIME was going through a reorganization and we just couldn't afford to wait three months for some of the decisions that had to be made. Is that right?

E. H. ROBIE: We will have had a Board meeting in every month except August, October and December. Those Board meetings have had so much important business that they each ran from three to seven hours.

J. H. MURRELL: Will it continue that way?

E. H. ROBIE: I don't think so. Six to eight meetings should be adequate in 1950.

J. H. MURRELL: There are some very large corporations which have Boards that have much more business than the AIME, and yet meet only once every three months.

E. H. ROBIE: I think that is entirely practical. The Executive and Finance Committee can meet for routine matters in the intervals, but we want to disabuse members of any idea that the Executive and Finance Committees and the Secretary are making policy decisions, and that the board is merely a rubber stamp.

J. H. MURRELL: Wasn't it planned that these Board meetings would be held in different sections of the country?

E. H. ROBIE: Yes, we plan to have an annual meeting every other year out of New York. We usually have a Board meeting at the time of the fall meeting of the Institute, and another meeting in some central place like St. Louis has been suggested. In that way we would have at least three meetings out of New York.

J. H. MURRELL: If the Board is going to meet in various places and meetings are to be fewer in number, I don't see the reason in the future for the great concentration of Directors in New York that we have had in the past.

E. H. ROBIE: I don't think that should be necessary.

CHAIRMAN ELKINS: One of the problems of this Committee is a reapportionment of the Directors through the Districts, and that has been seriously considered. I think every member of the Committee feels that the number in New York can be cut down in these days of fast travel. Suffice it to say that the Committee is seriously considering all the angles, and that whatever action is taken will be healthy.

As far as the Petroleum Branch is concerned, we are well fixed. With Charlie Millikan, Harold Decker and Gail Moulton as Directors — all of them for three years starting next February — and our Chairmen as they come along, I think we will be well represented and can keep the Board well advised of Branch opinions.

S. E. BUCKLEY: Eventually I think we will have an Institute structure in which the technical activities will be carried on entirely in the Branches, and the Branches will be the functioning units of the Institute. I think that is incompatible with geographical Sections of the Institute which are functioning now, and that those will have to be integrated together eventually in some satisfactory manner. We are beginning to see the crumbling at the edges — conflicts between Chapters and Sections, where Chapters align themselves with a technical activity and Sections represent a more diverse viewpoint. The thing that the Institute will undoubtedly have to strive for will be the preserving of what common interests there are among people of diverse technical activities, even though they carry on their work through the Institute in technical functions.

Looking down the road it seems to me as though, in line with the organization we now have, the Directors will eventually have to be representative of the functional Branches of the Institute rather than of the geographical Sections. I am a little reluctant, therefore, to see at this stage any freezing of the apportionment of Directors. As I understand the situation now, there is rather an unofficial understanding than a clear directive in accordance with the by-laws. The by-laws set up certain conditions, but there are certain agreements that go beyond the by-laws with regard to apportionment of Directors in the various geographical areas. If the present situation is working reasonably satisfactorily, it might be in

order to delay a final revision of the by-laws which would direct in detail the manner of election of Directors until such time as we are prepared to redraft the set-up entirely, with Directors appointed or elected primarily from the Branches rather than from the geographical areas.

P. ANDREWS: I think I might make a comment with reference to your remark that this Branch expansion situation will eventually be the rule more than it is now.

In the Southern California Section we have a very diverse group as far as technical interests are concerned. It is the largest Section in the Institute. Some years ago it was decided by the petroleum people that they had no direct voice or means of communicating their desires, so the Petroleum Chapter was formed by petition to the Branch. Through the years we have attempted to correlate the desires and requirements of the Petroleum Chapter with the Section, but we have found, after testing it in many ways, that it isn't too satisfactory.

This year the Chapter officially set up its own organization. It had a functional organization as far as officers and Council were concerned, but no direct contact or control over its own finances, mailing lists and things of that type, and there was some overlapping with the technical programs of the Section. So we simply followed suit and set the thing up on a Branch basis as the Institute did and, as a result of that action, the Executive Committee of the Southern California Section last Thursday voted to submit to the membership of the Section an entirely new set of by-laws which embody an organization on a Branch basis, in that the Board of Directors of the Southern California Local Section would be composed of the incumbent and the immediately past chairman of each of the three Local Branch groups. These six will be empowered to choose the seventh member who will be a Secretary or Secretary-Treasurer as desired. The officership within that group will then be chosen on a rotational basis. The Section itself, due to its diversity, will be simply a liaison group which will handle only affairs which affect the full Section membership.

E. H. ROBIE: I'm wondering what the situation would be if your Chapter embraced two Local Section territories. For example, this new Illinois Basin Chapter might be a part of the St. Louis Section territory and a part also of the Chicago Section territory.

P. ANDREWS: During this last year we have formed a subdivision of the Pacific Petroleum Chapter in the San Joaquin Valley, and started to work on such a sub-division in San Francisco. There is a sizable group up there, 50 or 55 people, who are principally men in the universities or men who have responsible positions in the home offices of several of the oil companies. Since San Francisco is organized as the San Francisco Local Section, it may be that the Pacific Petroleum Chapter will need to set up a method of dealing separately with each of the two Local Sections in California.

### *Petroleum Branch Directory*

CHAIRMAN ELKINS: I think you are adopting a precedent out there which some day will have to be integrated into the structure of the Institute. The next topic is a report on the 1949 Branch Directory.

W. H. STRANG: In February the Executive Committee instructed the printing of a Petroleum Branch Directory. The Directory was printed in June as a separate part of the JOURNAL. It cost $1,891. The Institute is planning to produce an Institute Directory next year and I presume therefore that we have no intention of producing our own Directory next year. We have placed with the Publications Manager, T. W. Lippert, the suggestion that the copies of the Institute Directory sent to the various Branch members bear a cover facsimile of the magazine of that Branch.

CHAIRMAN ELKINS: There is no question about the fact that we will not want to publish a Petroleum Branch Directory next year, is there?

S. E. BUCKLEY: I'm not sure. I attended the Board of Directors' meeting in San Francisco last year, at which there was considerable discussion of the Directory. It was dropped with reluctance by the Institute because of the cost. I don't recall the exact figure but I believe it was $12,000 to $15,000.

E. H. ROBIE: $12,000.

S. E. BUCKLEY: The Institute couldn't afford it so they did not put out a Directory this year. However, our action in publishing our own Directory was called to the attention of the Institute as a possible means whereby they could effect an economy in the issuance of Directories in the future. A specific suggestion was that the Directory in the future might a compilation of Branch Directories, which would cost the Institute a heck of a lot less than $12,000.

I am wondering if you are merely proposing next year to go ahead and spend $12,000 to publish a Directory, or are any steps being taken to either 1) have the Branches publish their own and group them together for an All-Institute Directory, or 2) take some other route that will not cost $12,000.

E. H. ROBIE: We are very definitely minded to reduce the cost of the Directory as much as possible. The Petroleum Directory cost in the neighborhood of $1,800 or $1,900, I believe, and that was for approximately one quarter of the membership. If it had been published for the entire membership it might have cost around $8,000.00. That's $6,000 less than our cost for the last Directory. One reason for that is that the pages which are in front of our Directory, about 115 of them, are not in the Petroleum Branch Directory. A lot of material might be omitted. We hope we can get our 1950 Directory out for around $8,000 or $9,000.

S. E. BUCKLEY: Did our Directory, which cost $1,900, come entirely out of Branch funds, or did it cost the Institute something?

W. H. STRANG: It was entirely paid for by Branch funds.

### *Section Delegates Council*

CHAIRMAN ELKINS: If there is no other discussion on that I would like to proceed to an account of the Gillson Report on Democratization of the Institute which was submitted in San Francisco to the Board of Directors, tabled and then resubmitted, in March or April. This report made several recommendations, one of which the Board finally decided was worthy of considerable further investigation. They dropped the point concerning the Secretary spending 40 per cent of his time out in the Sections, but they asked the Committee to go back and draw up a final report embodying its recom-

mendations concerning the formalization of the Section delegates.

The Committee circulated to 43 Sections a questionaire to which they got 13 replies. Based upon those replies and the spirit of the previous Section delegates' meeting, they set up a program which was approved by the Board and which will be put into effect immediately, for formalization of a Section Delegates' Council. They approved a set of by-laws which the Section delegates can revise if necessary after they get organized. It is provided that a Section delegate will be elected for a period of two years. Half the delegates will come on each year, so there will be an oriented group all the time. The by-laws provide for Delegates Council officers and for meetings at the annual and mid-year meetings, with traveling expenses paid for the delegates to the Annual meeting. The first meeting will be held in February in New York. There has been a question as to whether that was necessary, but the fact remains that the Section delegates have been clamoring for it, so the Board approved it. One of the Board members, I think, expressed to me exactly what I, too, think about it; that they have built up a tremendous hammer to drive a tack. The Section Delegates Council is independent of Branch organizations; it reports directly to the Board of Directors with its recommendations. The Chairman of the Council is invited to sit on the Board, not as a voting member but as an observer.

H. M. COOLEY: A while ago the Mid-Continent Section received a request to select a delegate for the Columbus Regional Meeting, which we did. When he asked us what he was to do, we were sorry to tell him that we had had no instructions, that we had nothing at all for him to do, except go there and observe what happened. He is back from that meeting and he reports that there was no Section delegates' meeting so he had nothing to report — no tack and no hammer!

### *Matters of Finance*

CHAIRMAN ELKINS: I should also mention that the Board allocated $1,000 for secretarial and office expense to handle the activation of this Section Delegates' Council. Let's proceed to the next item on the agenda. I would like to report briefly on the 1950 budget and related matters. For one thing, the accounting system in New York has now been set up so that we can know in a large measure all the money that is directly spent on Petroleum Branch functions. On general office expense they have a method of allocating salaries, etc., on the basis of services rendered, which has to be reviewed from time to time as conditions change. For your information I have made a few quick facts on Petroleum Branch income for 1949 based on eight months' actual expenditures, as compared with the budget we set up for this year. We have an income now from dues and initiation fees for eight months of $54,700, as against a budget estimate of $58,000 for the year. The advertising income for eight months was $12,100; in the budget it was $20,000 for the year.

On the sale of JOURNALS and Transactions to date we have an actual income of $12,400; whereas the expectation for the year was only $11,500. The Budget Committee is very happy to observe that our JOURNAL, Transaction orders and sales, etc., have done a lot better than was anticipated. Taking the whole picture, the total income of $86,000 in round numbers for eight months, indicates that we will probably have a greater income for the whole year than we figured. I'm not going into detail on the expense items, but the expenses so far, which include everything in Dallas, New York, etc., are $81,600 for eight months. Our budget provided $114,000 for the year. Actually, if you divide that out, it looks as though we may spend more than $114,000; it may be $120,000. We will be in the red this year, as anticipated before the year began.

You are aware that the Petroleum Branch has been on a campaign to get the deficit reduced in every way possible. You have heard the discussion on production of the Statistics Volume, which may save $5,000 to $7,000, with the other $1,500 we will have coming in. The Board has also taken another action which it means to follow; that is, that the Regional meetings, if they have them, and the Annual meetings will be self-supporting in so far as possible. We have been budgeted to the extent of about $3,000 to $4,000 a year as a Branch for the past several years for our pro rata share of that item, so there's a saving next year of $3,000 or $4,000. Increased dues next year, and new members paying dues, should increase income by about $114,000, which would balance the budget right there. But we don't want to balance it that way. We want to be able to take care of it some other way. Also, there'll be an increase in advertising, which may total $35,000 or $40,000, as compared to $20,000 this year. If that happens, the Petroleum Branch at the end of 1950 should be $15,000 to $20,000 in the black as far as an operating budget is concerned. Of course, we have been operating in the red for three years and we owe that money back. I don't know how they get that money, but they have ways of borrowing it some place up there. (Laughter)

J. H. MURRELL: How do they think we are doing up there, Mr. Robie?

E. H. ROBIE: They think you are doing wonderfully. The Directors are very pleased with what has happened in the Petroleum Branch this year.

J. H. MURRELL: You mean because we have stopped belly-aching? (Laughter)

E. H. ROBIE: I won't produce the reasons. (Laughter)

### *Differential Dues Assessments*

CHAIRMAN ELKINS: I would like to point out at this time — and I will point it out more formally in February — that I think the biggest problem facing the Institute and the Branches as they will be organized in the future is a choice of one of two things. At the present time the Metals Branch is running considerably in the red while the Mining Branch is in the black. Someday we will either have to have different dues assessment for each Branch, or we will have to cut the services of a Branch to fit its budget. I don't think that in an Institute such as ours it is right to have members of one Branch underwrite the services given to another Branch.

S. E. BUCKLEY: Maybe Mr. Robie is unprepared but I wonder if he could advise us as to whether there are being accomplished this year any effective economies in the Institute as a whole? Are the other Branches performing comparably? Are we looking toward a reduced deficit?

E. H. ROBIE: I think the deficit this year will be some

$17,000 less than last year, in spite of the fact that we have just taken on Mr. Lippert and a little additional expense in his department that amounts to some $10,000 for this year. There has been a good deal of promotional expense for the new journals, but on the other hand we have made certain economies. We have benefited little from reduced publication costs because printing costs are about as high as they ever were, and salary levels remain much the same. We have made some economies in paper.

J. H. MURRELL: Making a deficit of how much?

E. H. ROBIE: Well, there will still be a deficit of some $67,000

### *Thanks to the Southwest Texas Section*

CHAIRMAN ELKINS: Do we have a formal resolution drawn up on the next topic on the agenda?

V. H. DECKER: Yes, we have one. "Resolved that the Petroleum Branch, by action of its Executive Committee, expresses its appreciation to the Southwest Texas Section for arranging and conducting the excellent Fall Meeting in San Antonio, October 5-7, 1949". Does that sound all right?

CHAIRMAN ELKINS: That sounds fine. Do you move that that be adopted, delivered and publicized accordingly?

V. H. DECKER: Yes.

The motion was carried.

### *Comment on JOURNAL*

CHAIRMAN ELKINS: The next item was put on the agenda to see if we could discover what you don't like about the JOURNAL OF PETROLEUM TECHNOLOGY. What you do like about it we will listen to, but let's listen more to the constructive criticism, because we're interested mainly in improving the magazine. The Editorial Board and the Editors seriously want to hear everybody's criticism.

B. C. CRAFT: Mr. Chairman, the August issue is certainly one of our better issues. We still have about three pages devoted to News of AIME Members, and I feel that anyone in the petroleum business who subscribes to the trade journals would have access to this type of information. Since it costs about $35.00 per page for printing this appears to be expensive news.

CHAIRMAN ELKINS: The editors of the three magazines have gotten together and have made the recommendation to the Board that the personals of the entire magazine be divided so that each journal can handle its own personals. The Board tabled action on that until they had had a full year's study and history. They wanted to be sure that the membership at large felt as the editors did before they approved it. When next year's editorial policy comes up, that will be taken under consideration, will it not, Mr. Robie?

E. H. ROBIE: Yes, we have two serious matters to consider about the All-Institute Section. One is about the personals, and one is about the review articles which heretofore have gone into the February issue. There is a great difference of opinion. In general, with regard to personals, I find that people over, say, 40 years old will usually vote in favor of having all the personals in each JOURNAL. Young people who don't know as many people, usually only those in their own field, are almost unanimous in saying they are interested only in their own Branch personals.

H. H. POWER, AUSTIN, TEXAS: The men over 40 are all on the wrong side of the fence! (Laughter)

B. C. CRAFT: As far as I am concerned, I fail to see the advantage of including News of AIME Members in the JOURNAL, particularly that part titled "In Petroleum Circles." As I understand it, Mr. Chairman, the other part will be deleted.

CHAIRMAN ELKINS: No, I wouldn't say it is going to be; it's just one of two things under consideration at the moment. Instead of having two sets of personals in there you would have only the one. That would still leave all this information on Section activities, pictures of you at this Committee meeting, pictures at Local Section meetings, etc., which I think you are implying is a duplication of the trade journal reports.

B. C. CRAFT: Not exactly, but in this "Petroleum Circles" are the same things we see in the trade journals. I see no point in incorporating them in our JOURNAL.

E. H. ROBIE: When we published MINING AND METALLURGY we sent out questionaires to see what people liked best, and the personals were shown to be one of our most popular features. Therefore, that part of the magazine was built up to eight or nine pages a month when it had previously been only two or three pages, just because we had such favorable reactions.

W. H. STRANG: You do feel that the Local Section activity pages have value?

J. H. MURRELL: That's one of the most interesting parts of the magazine.

B. C. CRAFT: I think that's essential.

J. H. MURRELL: I think it should be stressed more and more that we should have better write-ups on that portion and cut down, as he says, on the personals about someone moving from one place to another.

S. E. BUCKLEY: That comes down to us from the New York office; we take it as it is.

C. V. MILLIKAN: I am interested in these personals. In discussing the question of publications with one of the editors of a leading trade journal the other day, he commented that their investigation of reader interest had revealed that the personals were outstanding, that they were ahead of every other section of his magazine.

Regarding the reporting, particularly of Section activities, which thus far has been, on the whole, the major part of your JOURNAL, I want to caution that, as interesting as it has been, you are still going to have to watch the way they are edited and published to avoid a declining interest. It is true that the JOURNAL is new, and that anything that is printed in it is very acceptable and will be for a certain period of months. But whether it will still be acceptable 10 or 20 months from now, I don't know.

Certainly the activities of the Sections are of primary interest to every member of the Petroleum Branch; however, not only the information that they had a barbecue or that they had a technical meeting, but more of the substance of the meeting. It's the latter that is of interest to the petroleum

engineer; the other is of superficial interest.

J. H. MURRELL: Wouldn't that come down to the point of the Local Section paying more attention to what is sent in?

C. V. MIILIKAN: Yes.

J. H. MURRELL: You want to be sure that what was talked about at a meeting is in the magazine. For instance, what you might be interested in, would be what they're thinking in a Section about reef limestone.

C. V. MILLIKAN: Yes, perhaps.

J. H. MURRELL: You want the conclusions that were reached to be published in the paper.

C. V. MILLIKAN: I have no complaint on what has been published. I am not being critical. I am only cautioning of something which I think might possibly develop or which may have already developed with hardly a realization.

S. E. BUCKLEY: Is it in part that there is too great a similarity from month to month in the manner and nature of the presentation?

C. V. MILIKAN: I think that's it.

J. H. MURRELL: That's the local view of reporting.

J. B. ALFORD: I am very glad to have your comments, Mr. Millikan, as an editor of the JOURNAL. We are most anxious to determine the appropriate material for the Local Section pages. We had reached the conclusion that it was, just as you say, a summary of what the speakers say at these meetings. Of course, we'll cover the meetings pictorially also, but to my mind the true significance of the Local Section pages is the technical material that is published there. We have developed in the last six months a reporting guide which should be very helpful.

S. E. BUCKLEY: I think the JOURNAL should contain not only something about the text of the speech, but also the reaction of the group.

J. H. MURRELL: Do you think it is important enough — I do — to review the material carefully when it comes in and before it's put in the JOURNAL?

S. E. BUCKLEY: How do you get it now?

W. H. STRANG: Direct from the Local Section JOURNAL Secretary in most cases.

E. N. DUNLAP: My feeling is that the importance of the JOURNAL Secretary's job has not been sufficiently emphasized. He should be not only a man who likes to write, but one who has the ability to write and also the time.

T. D. MUELLER: Proofreading of technical articles, I think, has slipped.

W. H. STRANG: That is true. We have been trying, however, to establish systems and procedures whereby all typographical errors will be eliminated. I feel we have made some progress in that direction. Your comments don't refer so much to the last few issues, do they?

T. D. MUELLER: No.

W. H. STRANG: Probably more to the first of the year than the last three or four months. At the first of the year we simply didn't have time to send proof to the author for proofreading, which is certainly something you must do. We are confident that we can overcome our previous difficulties with regard to proofreading, which have been problems caused by acute shortage of time.

P. ANDREWS: I feel the reporters from the Sections should be selected with very great care. I would like to also suggest that if more "meat" is added, which is desirable, and that if the discussion is also added, the authors of the papers and the people who comment on those papers be given an opportunity to edit their remarks before they are sent to the JOURNAL.

W. H. STRANG: Where a speaker is to be reported as saying something of general significance, the JOURNAL Secretary should call him up and let him verify his statements. In the past we haven't checked upon some things that looked a little awry to us; we depended on the JOURNAL Secretary. I think it might very well be discouraging to him to hear from us every time we hear from him.

S. E. BUCKLEY: Since this is somewhat in the nature of spot reporting, would it be feasible in every case to have these matters proofread?

W. H. STRANG: I think not. The best that can be done is to have some after-meeting contact between the JOURNAL Secretary and the speaker. In many cases the speaker will be there tonight and gone tomorrow.

### *Technical Notes*

CHAIRMAN ELKINS: Are there any other comments on the JOURNAL at the moment? If not, let's proceed to the next point, the recent suggestion of matter including Technical Notes in the Transactions Volumes.

J. H. MURRELL: I move that the Technical Notes be handled as they have been in the past.

CHAIRMAN ELKINS: You mean, submission as a technical paper?

J. H. MURRELL: Yes.

J. E. SHERBORNE: It seems to me that some of these Technical Notes are as important as the papers themselves. I don't think there is a suitable compromise that can be reached on that.

C. V. MILLIKAN: Certain things do not qualify as technical papers but are merely progress reports, not finished products.

W. H. STRANG: We can do something intermediate between including Technical Notes in the *Transactions* and excluding them from the Transactions, that is to go ahead and publish the Notes as they come in, as we are now doing, and at the end of the year let the Publication Committee decide which of them should be included in the *Transactions*. After the Committee selection of certain Notes for inclusion we would make up, by offset printing, a section of 12, 16 or 32 pages for binding in the *Transactions*.

CHAIRMAN ELKINS: Is that essentially what you intended by your motion?

J. H. MURRELL: That is exactly it.

The motion was carried.

S. E. BUCKLEY: I vote no. I don't think the issue is quite clear-cut enough to be unanimous. I think that if it is a matter of permanent interest, written up as a Technical Note, it

should be incorporated in a technical paper and not published as a Technical Note. A Note is usually no more than a progress report on an investigation which will later be incorporated into a complete paper on the subject.

J. H. MURRELL: My motion was to set a policy and let the Publications Committee make the decision at the end of the year as to how it should be handled.

S. E. BUCKLEY: That means they will have to review all the notes.

J. H. MURRELL: No, only those that somebody desires to have published in the *Transactions*.

MORRIS MUSKAT: I don't differ with the vote that was taken, but I do think it is worthwhile to mention that there may be more to a Technical Note than merely a reflection of someone's laziness in not writing a complete paper, as has been suggested. It is normal practice in some of the Societies to devote rather extensive sections to so-called Letters to the Editor. In 4 recent issues of the *Physical Review* 120 Letters to the Editor were published as compared to 95 full papers, and in 4 concurrent issues of *The Journal of Chemical Physics* 54 Letters to the Editor were published as compared to 50 full papers. I think the Technical Notes could be considered as equivalent to such Letters to the Editor. Frequently the presentation of only one or two paragraphs in length are of as much value as a complete technical paper, and I think the Technical Note offers an opportunity to present something quickly for publication without having to wait six to nine months to incorporate it into a technical paper. It helps to get pertinent information out in a hurry. I do think, however, that it would not be a serious limitation if the Technical Notes were reviewed before subsequent publication in the bound volumes, although in the case of the Institute of Physics journals the Letters to the Editor are paged in sequence to the full papers with the implication that when bound they would be reprinted as originally published, and without previous refereeing.

The next item on the agenda was a discussion of the procedure used in solicitation and acceptance of papers for Branch meeting programs. This discussion was participated in by L. E. Elkins, S. E. Buckley, J. E. Sherborne, P. Andrews, V. H. Decker, J. H. Murrell, M. Muskat, Claude Hocott, C. V. Millikan and B. C. Craft and terminated in a decision to consider the matter further at the 1950 Annual Meeting.

### Proposed Change in By-Laws

J. H. MURRELL: I would like to bring up a change in the By-Laws which I think is necessary and which can be done according to Article X.

In going through the By-Laws I find no provision for a Treasurer or for a Secretary of our Petroleum Branch. I would like to propose that Article V of the By-Laws — Officers, which reads now: "Section 1. The officers of the Branch shall consist of a Chairman and two Vice-Chairmen" — have added to it "a Treasurer and a Secretary." Then in Article III — Funds, which reads: "Section 1. The expenditure of funds received by the Petroleum Branch shall be authorized by the Executive Committee of the Petroleum Branch." You can make some appropriate statement reference the Treasurer. I think that many Executive Committees have their Secretary as an ex-officio member, and I think the Treasurer should be an ex-officio member also. That would not change a thing. You could just say in Section 2 of Article V — Officers, the following: "The Executive Committee shall consist of the officers." You have a Secretary and a Treasurer and they will be officers of the Branch.

CHAIRMAN ELKINS: May I suggest that you get together with the Secretary and draft your proposed changes. Then we will circulate the proposal to the Executive Committee and follow it through.

J. H. MURRELL: I think we ought to make provisions in our By-Laws for a Secretary and a Treasurer, if we have them, so that the By-Laws will reflect exactly what we are doing.

W. H. STRANG: The Executive Committee can propose a change in the By-Laws but to actually change them you have to take a vote of the membership. One reason why we haven't brought some of the important provisions of the Operating Manual forward into the By-Laws is because it costs money to take a vote and we thought we'd wait until we had an accumulation sufficient to justify the expense. Maybe we have now.

### San Antonio - Austin Section?

H. H. POWER: Two years ago Bill Strang, John Murrell and several of the rest of us met in San Antonio for the purpose of coming to some decision as to whether or not a Section should be formed here — an Austin-San Antonio Section. However, our group was small and we just let the matter go.

We have about 20 active members in Austin, including the Student Associates, and in San Antonio I would guess we have 30 or 40 members. However, most of the membership here is involved in the Southwest Texas Geological Society. They hold monthly meetings and also weekly luncheons. It would be difficult to get that membership, which is composed mostly of geologists, to separate engineering meetings, but on the other hand it might be possible to work through the Southwest Texas Geological Society in some sort of an alternating proposal.

I don't want to go into a long discussion of this, but I would just like to drop a few seeds here right now to start some active thinking toward the organization of a Section here — possibly a Chapter. However, I would say a San Antonio-Austin Section. I think we need it because of the same situation here as in West Texas — the isolation of San Antonio and Austin from other areas.

### Suggestions Wanted

CHAIRMAN ELKINS: Is there anything else to come up before the meeting?

E. H. ROBIE: The Mudd Fund for years has been giving free volumes to all new Junior Members — sets of two to four volumes. In recent years there has been no book whatever of specific interest to petroleum engineers. The Mudd Fund Committee would like to have the Branch suggest an author and title for a book to be published, and to be paid for by the Mudd Fund, for free distribution to Junior Members in the Petroleum Branch, which will be of specific professional interest to them.

The meeting adjourned. • • •

One
West
Branc
in Lo
Octob
Atten
pecte
400 m
ments
was
techni
terest
ferent

1. F
for th
Town
ber 20

2. A
eon w
ternat
son, T
Harcu
ternat

3. C
ston,
Oil C

4. T
V. Sn
caugh

5. T
are L
J. H.
Hill,
Bill F
of Sch

6. T
who p
agem
Hanc
Parke
Thach
In ad
borne
and F
chairm

7-15
tion
party
dezvo
on Oc
of th
tendi
it wa
held b

Decem

## BRANCH MEETING IN LOS ANGELES

One of the outstanding features of West Coast activity in the Petroleum Branch is the Annual Branch Meeting in Los Angeles, held this year on October 20 and 21 at the Elks Club. Attendance was larger than was expected, with a total registration of 400 members and guests, and all comments heard indicate that the meeting was an outstanding success. Eight technical papers and two general interest papers were presented in different sessions of the two days.

### Pictures at Left

1. Paul Andrews serving as M. C. for the Branch Luncheon held at the Town House in Los Angeles on October 20, first day of the meeting.

2. Among those attending the luncheon were L to R: Frank Smith, International Cementers; R. B. Hodgson, Tidewater; F. M. Carlisle, Robert Harcus and R. L. Gollum, all of International Cementers.

3. Cecil Weaver, left, of M. O. Johnston, and H. F. Dangberg of Hancock Oil Co. discuss a point at the meting.

4. T. H. Acres of Barnsdall, and S. V. Smith of Pacific Perforating, also caught in a discussion.

5. Taking the opportunity to relax are L to R: Clark Edgecomb, Jr., and J. H. Gallois of Schlumberger; R. C. Hill, Eastman Oil Well Survey, and Bill Plasch and Kenny O'Bert, both of Schlumberger.

6. Three of the Chapter members who participated in the excellent management of the meeting: left, Ray Hancock, exhibits; center, Frank S. Parker, publicity, and right, John H. Thacher, general meeting chairman. In addition to these, John E. Sherborne served as program chairman, and H. J. Stroud as arrangements chairman.

7-15. The outstanding social function for the meeting was a cocktail party and dinner dance in the Rendezvous Room of the Biltmore Hotel on October 21. Pictured here are many of the 224 members and guests attending, who unanimously agreed that it was one of the finest parties ever held by the Chapter.

# San Joaquin Valley Section Activities Pacific Petroleum Chapter

By C. L. Doyle

The newly formed San Joaquin Valley Section of the Pacific Petroleum Chapter held its first meeting November 8, at the Bakersfield Inn, Bakersfield, California, with 30 members and over 70 guests present. The San Joaquin Geological Society joined in the meeting, with some 20 members present.

Chairman Murray Putnam of the Standard Oil Co. of California reviewed the background of the formation of the section which occurred at an informal gathering in February, 1949. Selection of the initial panel of officers was by a nominating committee appointed by Paul Andrews, chairman of Pacific Petroleum Chapter.

Following the dinner, J. E. Walstrom, Well Logging Consultant for the Standard Oil Co. of California spoke on "The Electric Log — Its Advantages and Its Limitations".

The talk was a general discussion of the electric log and the curves obtained, and is summarized as follows:

**J. E. Walstrom spoke on well logging at the initial meeting of the Section. After a B.S. in E.E. from New Hampshire University, he received an M.S. in Physics from Wesleyan University, and did graduate work at C. I. T. He worked with Schlumberger for 10 years and then joined Standard Oil of California as a well logging consultant.**

### *The Resistivity Curves*

Usually three resistivity curves of different electrode configuration are recorded. These curves would be almost identical except for the presence of the mud column ("hole effect"), the presence of an invaded zone adjacent to the bore-hole ("invasion effect"), and because of the finite thickness of sedimentary layers ("bed thickness effect"). Seven variables enter into these effects, (1) the hole diameter, (2) the mud resistivity, (3) the distance of invasion, (4) the resistance of the invaded zone, (5) the bed thickness, (6) the ratio of true resistivity of the bed in question and surrounding formation, and (7) the electrode spacing.

When a sand contains some oil its resistivity is always greater than when it is fully wet. A convenient rule of thumb is that a clean oil sand with less than 50 per cent interstitial water will have a resistivity of at least twice that of the same sand fully wet. For sands with no argillaceous material the ratio will be more nearly four.

The resistivity of a wet sand has been assumed proportional to the resistivity of the water it contains. This proportionality factor, called the "formation factor", is determined by its porosity and the distribution and shape of the porous channels. Recent research has indicated this F-factor may not be independent of the resistivity of the saturating medium. If this is true the F-factor can no longer be looked upon as a constant.

### *The Potential Curve*

Naturally occurring potentials in bore holes are a sum of (1) the potential across the shale, (2) the liquid boundary potential between the drilling mud and the formation water, and (3) a streaming potential established by the pressure drop across the filter cake.

With normal clay-base mud a good indication of potential opposite a particular horizon usually indicates the

*(Continued on Page 41)*

**Members of the panel for the November 10 meeting were L to R: H. D. Aggers of Union Oil, Randolph R. Smith of Seaboard, and E. J. Bemiss of Standard Oil of California.**

# Junior Group Activities
# Pacific Petroleum Chapter

By I. A. Marshall, Jr.

An educational panel discussion was the featured program for the November 10 meeting of the Group in Downey, California. The panel consisted of E. G. Bemiss, Standard Oil Co. of California, H. D. Aggers, Union Oil Co., and Randolph R. Smith, Seaboard Oil Co. The meeting was opened by the chairman, who welcomed the 95 members and guests, and turned the meeting over to the panel.

### *Well Washing*

The first speaker was E. G. Bemiss of Standard Oil Co., who described his experiences with the washing of low gravity wells having unconsolidated sands and interbedded, incompetent, shale bodies. He pointed out that well washing becomes more and more important as the production of a well passes the flush period and approaches the economic limit. The basic purposes of well washing are twofold: the removal of drilling fluids, filter cake, and cuttings from the well bore after drilling and, secondly, the removal of asphalt residues, sloughing sands and shales and any material which accumulated after the well was put on production. The degree of plugging of the sand faces at the well bore has been considerably reduced by the improvement of drilling fluids, i.e., low water loss muds and muds with oil filtrates. However, all drilling fluids must necessarily form some filter cake which materially reduces the permeability at the sand face. In presenting his conception of the plugging phenomenon in gravel packed (pre-packed) liners, Bemiss described the condition of the hole at the time drilling is finished and the liner is being run. At this time the incompetent shales and unconsolidated sands are held in place by the mud column. However, upon removing the mud and putting the well on production, some sand and shale immediately sloughs into the annulus between the outside of the liner and the well bore. Thus the annulus is filled with detritus consisting of shales, sands, various argillaceous materials, precipitated salts, asphalt residuals, and oil. Thus there is formed a mass of material which has no permeability relation to the original pay zones. To enter the well bore the produced oil, gas, and water must pass through this material. Plugging of this kind has caused the production from one lease to decline from 8000 B/D to 25 B/D in a matter of several years. By calculation of the oil in place, it is obvious that such a decline is not normal. Also, in cases where this rapid decline has been experienced, new wells drilled on a five-spot pattern will have an initial production very similar to the original wells and will be clean whereas the original wells may have an appreciable water cut. Redrilling of wells which have become plugged is not uncommon but it is obviously a very expensive solution, often times having poor results unless the well is whipstocked to open up clean sand faces. The most practical and cheapest solution is to remove the plugging material by one of the many washing methods. Although comparative data is difficult to accumulate on the effectiveness of various well washes, it has been well determined that the best time to remove the plugging materials is at the time of completion of the well. Various

**Pictured here are a few of those attending the November 1 meeting. L to R they are: W. E. Perkes, W. E. Woodruff, J. C. Elliott, Paul Schwemler, Jud White, Don Yeo and Fred Long.**

types of well-washing chemicals and methods are available but it is imperative that the operator have some knowledge of what is causing this plugging, so that the proper method can be selected. In the opinion of Bemiss, the ideal well wash should have the following characteristics: (1) a cleaning or detergent action, (2) low surface tension to reduce the possibility of forming water blocks, (3) it should not hydrate (swell) included clays or bentonites, (4) should not form emulsions with the well fluid, and (5) should be non-toxic to personnel handling it. A mechanical agitater is commonly used with the various well washing liquids and many types are available. Some of the agitating tools in common use are: circulation washers (commonly used with oil), mechanical pressure washers used with either oil or washing solutions, and mechanical "surges" used with either oil or washing solutions. Circulation washers are not too desirable because they only give a jet action and necessarily maintain a high fluid head against the formation. Mechanical pressure washers are considered to be better because they give a surging action without maintaining a high fluid head. Bemiss described a relatively new innovation in well washing known as the "gas pack" which involves the relatively slow (2 to 3 second) combustion of a gas-forming material which surges the chemical or oil in the well bore through the liner and on dissipation of the gas pressure the fluid surges back into the hole carrying the plugging materials with it. Very little work has been done with this method so its results are still in doubt. Of the well washing jobs in which Bemiss has been personally involved, 40 per cent were considered good, 15 per cent marginal, and 36 per cent doubtful. However, the 49 per cent were so successful that they more than paid for the marginal and doubtful jobs.

The meeting at this point was turned over to a representative of Long Beach Oil and Development Co., who showed photographs of the experimental, surface washing of one 20-foot and two 10-foot sections of 6⅝-in., pre-packed gravel liners recovered after one year of operation in a Ranger zone well in the Wilmington field. The tests consisted of suspending the plugged sections of liner in a derrick and washing through the liner with 27° oil using a mechanical pressure tool. It was found that the perforations broke down at 450 psi and final washing was continued at 175 psi. As far as can be determined, this was the first formally conducted test in which an actual plugged liner was recovered and washed at the surface where the action of the washer and its effectiveness could be observed and photographed. The most significant fact obtained from this experiment was that a liner tends to break down over only a fraction of a circumference thus leaving, in some cases, a large portion of the area of the liner still plugged. Production entering the well thus has to travel in a circumferential direction to a point in the liner where it has access to the well bore. As pointed out by Bemiss, the annulus between the liner and the original well bore is filled with sand, shale and other material which tends to impede flow around the circumference of the liner.

### *Acidizing*

H. D. Aggers of Union Oil Co. spoke briefly on the different aspects of acid treatment with string shots and perforation cleaning with knife-type tools. He pointed out that acid should only be used in zones where it could be expected to have some action on the zone and that use of acid in non-reactive formations is not only costly but might have detrimental effects. The use of acid in conjunction with a string shot was first used in 1947 and, although operators differ in the method of use. the most common practice is to first bail the hole clean and then spot the acid and set off the string shot. Some operators prefer the use of a light oil, such as diesel fuel, in preference to the acid and, of course, in the case of non-reactive zones, the use of light oils is recommended. The procedure in detail consists of bailing all sand or other material from the well then the string shot is run in and out of the hole to be sure that sufficient clearance exists. The tubing is then lowered to the bottom of the liner and 15 to 20 per cent excess acid is spotted in the liner, and the string shot is again introduced and set off. The well is then put on production immediately. The 22,500 fps velocity of the string shot results in the penetration of many of the impermeable zones which would normally not be penetrated by high volume or a high pressure washing.

The use of knife-type perforation cleaners is recommended for the removal of clogging material in slotted liners. This method is particularly effective for removing scale, hard sands, or shales and it has been the practice in some fields to run this tool prior to washing to insure that the liner is open. Opening clogged liners with the knife method is also considered good insurance against liner failures because the velocity of the fluid entering the liner is kept to a minimum.

### *Formation Fracturing*

To complete the discussion of well completion and reconditioning methods, Randolph Smith of Seaboard Oil Co. described his company's experiences with formation fracturing in the Bandini Hills field. The purpose of formation fracturing is to increase the entry rate to the well bore by fracturing the pay zone through the injection of oil at a high volume and pressure. The well selected for this testing was about 8000 feet deep and was produced from hard, relatively impermeable sand and, at the start of the test, was flowing by heads. After formation fracturing had been completed and the injected oil recovered the well production showed a substantial increase with no increase in gas-oil ratio; however, the production decline was unchanged. The total amount of additional oil recovered by this method was 2600 barrels. The cost of the operation was approximately $3600 and indicated a payout period of 41 days. A second attempt was made to fracture this well using twice the injection rate; however, there was no indication of further fracturing. From the data presented, it appears that this form of secondary recovery has a definite possibility of success. However, there has not been a sufficient number of wells fractured to completely evaluate the results. A more comprehensive review of Smith's talk appeared in the November JOURNAL under Pacific Petroleum Chapter Activities. ★ ★ ★

# Delta Section Activities

By J. Paul Ratliff, Jr.

A panel discussion covering various phases of offshore lease development drew a record attendance of approximately 140 members and guests to the November 8 meeting of the Delta Section. The capacity of the New Orleans Petroleum Club was taxed to accommodate this large crowd of engineers interested in exploitation of the Continental Shelf.

H. M. Krause, Jr., assistant division petroleum engineer for Humble Oil and Refining Co. at New Orleans, was the very capable moderator who successfully coordinated contributions of the following oil company representatives: C. P. Besse, chief construction engineer, The California Co., New Orleans, La.; B. K. Ayers, chief marine engineer, Stanolind Oil and Gas Co., Houston, Texas; D. F. Dial, Jr., construction engineer, offshore, The Pure Oil Co., Houston, Texas; W. E. Harpst, area mechanical engineer, Shell Oil Co., New Orleans, La.; R. B. Pierce, mechanical engineer, Magnolia Petroleum Co., Dallas, Texas; J. C. Posgate, division petroleum engineer, Humble Oil and Refining Co., New Orleans, La.; J. H. Rambin, assistant division manager, The Texas Co., New Orleans, La.; W. C. Roome, assistant offshore drilling superintendent, The Pure Oil Co., Morgan City, La.; Thomas Seale, offshore drilling superintendent, Kerr-McGee Oil Industries, Inc., Oklahoma City, Oklahoma.

### Drilling Platforms

The panel was opened with a discussion of drilling platform types and designs by D. F. Dial, Jr. Four types of platforms have been used to date in connection with offshore drilling and production operations, (1) The original Pure - Superior - Creole platform constructed in 1937 with all bracings above water (platforms of this type are now considered obsolete). (2) The Williams-Humble four-pile jacket type platform. An example of this type construction is the large self-contained platform off Grand Isle which was Humble's first platform. (3) The McDermott pipe template type platform (e.g. as used by California and Superior), and (4) The Brown & Root truss and cable type platform as used by Stanolind.

In the general discussion by Ayers, Besse, Dial and Posgate it was brought out that the cost of erecting offshore platforms varies greatly depending upon size, type, depth of water, weather, etc. Actual costs of platforms constructed to date in the Gulf of Mexico have varied from approximately $125,000 for small structures used with drilling tenders to approximately $1,230,000 for the most expensive multiwell self-contained structure.

### Drilling Tenders

A discussion of the types of drilling tenders and anchorages was led by W. C. Roome and J. C. Posgate. Two types of ex-Navy vessels have been converted for use as drilling tenders — YF and LST. The YF barges are all non-self propelled. LST's are both propelled and non-propelled. Two main purposes are served by all of the tenders (1) crew quarters and (2) storage of material. Among other uses of the tenders are (1) platform construction, example, Pure Oil Co., (2) mud circulating and storage facilities, (3) auxiliary power plant and (4) well service facilities such as cementing and logging equipment. C. P. Besse pointed out that the

**Pictured above are participants in a panel discussion on offshore development presented at the November 8 meeting of the Delta Section. L to R, standing, W. E. Harpst, Shell; C. P. Besse, The California Co.; W. C. Roome, Pure Oil; J. H. Rambin, The Texas Co., J. C. Posgate, Humble; R. B. Pierce, Magnolia; L to R, seated, D. F. Dial, Jr., Pure Oil; H. M. Krause, Jr., Humble; Thomas Seale, Kerr-McGee Oil Industries; B. K. Ayers, Stanolind.**

plan of action in the event of a hurricane is the determining factor in deciding whether or not a drilling tender should be self-propelled. Experience has shown the two methods to be about equal from an economic standpoint — the high cost of tugs with a non-propelled tender offsetting the cost of maintaining a full crew and engines on a self-propelled vessel.

Anchorages used with offshore drilling tenders are of two general types, with several combinations of the two in use by various operators. These mooring designs employ stud link anchor chain or wire rope cable operated by windlasses or winches on deck and connected to spud piles or heavy anchors. The first mooring design used in the Gulf consisted of wire rope cables extending from winches aboard ship to fixed pilings driven in the ocean floor around the tender. This has been progressively modified by various operators to provide for (1) the use of large surge buoys in the cables between drilling tender and piling, (2) stud link anchor chain from the pilings to the buoys, and (3) double wire lines from shipboard to sheaves on the buoys. Although the original installation of wire rope mooring equipment is much less expensive than anchor chain and windlasses, the latter method is definitely safer and provides a much more flexible mooring arrangement. The use of multiple-wildcat electric driven anchor windlasses with stud link anchor chain attached to spud piling is apparently the most effective mooring system in use at this time. It was pointed out, however, by J. C. Posgate that the great loads thrown on mooring chains in deep water plus the constantly recurring fatigue stresses make it advisable to pay very close attention to the mooring problem.

### Marine Transportation

Thomas Seale presented many interesting facts pertaining to his company's marine transportation problems. Kerr-McGee's experience with 63-foot and 85-foot wooden hull crew boats over a period of eighteen months has shown the operating costs to be practically identical, including depreciation, insurance, crew, fuel, etc. Other operators report operating costs in the same range for crew boats, i.e. $100.00 per day. C. P. Besse joined Seale in praising the LCT as a most useful vessel for handling offshore cargo. The LCT operating costs approximate $200.00 per day. The operating costs of the 84-foot ex-Army ST tugs used by Kerr-McGee average about $350.00 per day, while the YF tenders run close to $600.00 per day. The above figures are approximations furnished by one operator only. Operating costs of LST tenders would, of course, greatly exceed the above figures. J. C. Posgate added that marine transportation, comprising from 20 per cent to 30 per cent of the cost of offshore wells, averages $500.00 to $1200.00 per rig per day. The cost per barrel per month of both leased and company owned oil barges was analyzed by Seale. Experience has shown this cost to r unas high as 30¢ per barrel per month not including tug or lifting charges.

### Drilling and Production Practices

Led by R. B. Pierce the discussion of offshore drilling practices revealed very little deviation from standard drilling practices on land jobs. Setting of an extra string of protective casing and the use of sea water in drilling mud by some operators are the principal differences. Thomas Seale evoked considerable comment with a suggestion that only two or three wells be drilled from any one platform. C. P. Besse and J. C. Posgate disclosed that directional deviations of 30° to 40° are being achieved in offshore locations where as many as ten wells are drilled from one platform.

The discussion of offshore production practices was directed by C. P. Besse who told of the 4 in. pipelines which his company has installed to carry crude oil inshore from two offshore structures. These lines were used instead of barges because the fields, which are relatively close to shore, show indications of producing large quantities of oil over a long period of time. Other operators are using production barges to transport the offshore crude to shore storage. In both cases oil and gas separators and a nominal amount of oil storage are provided either on the producing platform or on adjacent small platforms. Two factors of prime importance in offshore production are safety and conservation of manpower. Both will be served by the increased usage of automatic production controls.

### Effect of Weather

J. C. Posgate elaborated upon the effect of weather on drilling and producing operations stressing Humble's experience with line squalls and hurricanes. Other than routine navigational hazards such as fog and rain, weather for the offshore operator may consist of northers, line squalls, or hurricanes. Humble Oil and Refining Co. has in operation a comprehensive weather forecasting service which supplements and cooperates with the U. S. Weather Bureau. Over a two-year period Humble's twice-daily forecasts of offshore wave heights have been 91 per cent correct within the allowable 1½ feet. Radar is used in predicting weather conditions within a 300-mile radius as well as to direct vessels in inclement weather. The 3 cm radar sets used on Humble vessels have proved very satisfactory. The necessity of accurate weather predictions became apparent when Posgate pointed out that from 18 to 30 hours are required to evacuate a location and all personnel transfers must be completed before wave heights exceed nine feet. A general discussion of the advisability of raising platform levels higher than now used as added hurricane protection evoked comment on both sides of the question.

B. K. Ayers and J. H. Rambin conducted a very interesting discussion of communication methods and types of equipment. Frequency modulated radio installations are used for communicating between shore bases, vessels, and platforms. This type of equipment gives static free reception at all times. Marine radio-telephone service is also installed on vessels to facilitate communication with other vessels and the Coast Guard.

### Research and Development

Many of the offshore operators are conducting research on various phases of offshore drilling and production. W. E. Harpst described some of the problems Shell has encountered in shallow

*(Continued on Page 41)*

# Permian Basin Section Activities

By Tom Flewharty

John L. P. Campbell with Lane-Wells Co. in Houston presented a paper entitled "Interpretation of Radio Activity Logs in the Limestone Reservoirs of West Texas", at the November 14 meeting of the Section in Odessa, which was attended by 139.

Chairman Tom C. Frick announced that election of officers would be held at the next meeting, and appointed the following nominating committee: Berte Haigh, University Lands in Midland, chairman; R. S. Dewey, Humble Oil and Refining Co. in Midland; and J. C. Wright, Garrett Oil Tools in Odessa.

A partial condensation follows of Campbell's paper, which was also partially reviewed on the North Texas Section Activities page of the July JOURNAL.

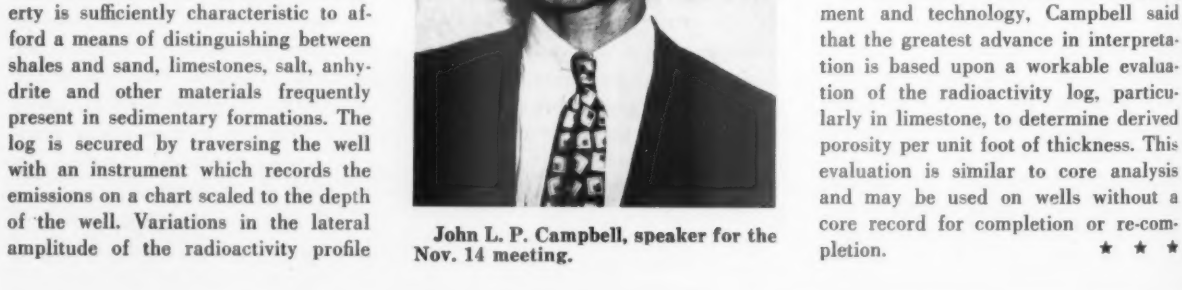
The basis of the radioactivity log is the fact that all rocks display some degree of radioactivity, and this property is sufficiently characteristic to afford a means of distinguishing between shales and sand, limestones, salt, anhydrite and other materials frequently present in sedimentary formations. The log is secured by traversing the well with an instrument which records the emissions on a chart scaled to the depth of the well. Variations in the lateral amplitude of the radioactivity profile will develop a pattern that is characteristic of the formation penetrated. Sands are low in radioactivity values and shales higher, but the record of these formations appear similar on radioactivity and electrical logs.

In the actual logging gamma ray and neutron curves are obtained separately. There is no base line to the gamma ray curve, and the darker the color of the formation, the higher the radioactivity. The base line of the neutron curve is shale. It is difficult to tell from this curve alone whether the formation is fluid or shale, and the neutron curve by itself is inadequate. Gamma ray curves by themselves are best correlated with the amplified normal curve on the electrical log as a substitute for a potential curve.

**John L. P. Campbell, speaker for the Nov. 14 meeting.**

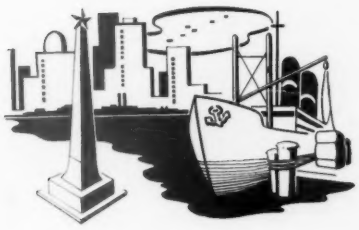
Among the 19 applications of the log are bore hole measurements, locating cased off prospective sands and limes, to trace cement, plastic or mud after pipe is set, for casing seats, liner overlap, parted pipe, and to make structural studies through correlations locally or regionally. Another application is the obtaining of stratigraphic information to find fluid bearing zones.

In discussing improvements in equipment and technology, Campbell said that the greatest advance in interpretation is based upon a workable evaluation of the radioactivity log, particularly in limestone, to determine derived porosity per unit foot of thickness. This evaluation is similar to core analysis and may be used on wells without a core record for completion or re-completion. ★ ★ ★



**A part of the group attending the November 14 meeting of the Permian Basin Chapter.**

# Gulf Coast Section Activities



By J. E. Kastrop

One hundred and thirty-three members and guests filled the Houston YMCA Auditorium to attend the Section's November 15 meeting. Owen Thornton, chairman, presided, and the business meeting opened with a report from R. L. Whiting, program chairman of the All-Texas Sections Meeting. The 1949 meet will be held at College Station December 8 and 9, and the general theme will be completion practices and associated problems. Eleven technical papers will be presented and will include such subjects as logging, coring, mud control, acidizing, jet perforating, and cementing. Highlighting the program will be the annual student paper contest sponsored by the Gulf Coast Section. This year's meeting will see three schools competing for top honors: The University of Texas, A&M College of Texas and Texas Technological College.

The report on the Section-sponsored discussion group on reservoir engineering stated that Norman Clark of Humble had been made program chairman. The group will make detailed studies into such problems as sampling, subsurface fluids and laboratory techniques.

The 1950 Section chairman, Section delegate, two vice chairmen, a secretary-treasurer and two directors were elected at a meeting on December 13. Members of the nominating committee appointed by Chairman Thornton are: Chairman, George L. Nye, City National Bank; G. D. Robertson, Shell Oil Co.; Robert L. Hoss, Humble Oil and Ref. Co.; Herman Otto, Tennessee Gas Transmission Co.; and Asbury S. Parks, Consultant. Announcement of the new officers will be made in the January JOURNAL.

The Gulf Coast Section delegate, along with the delegates from the Pennsylvania Anthracite Section and the Boston Section, will act as a nominating committee in the selection of a chairman, a vice chairman, and a secretary for the delegates council plus members for the executive committee.

**J. Ben Carsey, chief geologist, Humble Oil and Refining Co., spoke on "Geology of the Gulf Coastal Area and the Continental Shelf", at the Gulf Coast Section meeting on November 15.**

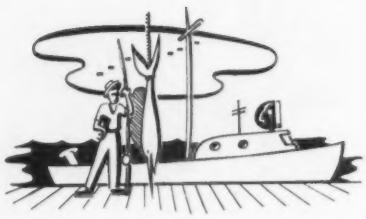
The largest single contributing factor to this most successful meeting was the principal speaker and the subject on which he has made extensive investigations. J. Ben Carsey, chief geologist, Humble Oil and Refining Co., is an "oil-finding" geologist, said Stuart Buckley of the same company as he introduced the speaker. Carsey has been associated with Humble since his graduation from The University of Texas in 1925. He was the company's first division geologist when Humble organized its West Texas Division in 1927, as well as the first division geologist when the company opened its Louisiana Division in 1941. In 1948, Carsey organized Humble's exploration campaign when the company became active in California. He was made chief geologist in November of 1948.

Introducing his subject, "Geology of the Gulf Coastal Area and the Continental Shelf", Carsey stated that it was necessary to look at the geology of the area and at the many salt domes which are found there to evaluate the importance of the continental shelf and the Gulf Coast area of Louisiana and Texas. The coastal plain bordering the Gulf varies in width up to 100 miles and slopes gently at about five feet per mile until it reaches the coastal swamps and finaly the open sea. The speaker employed about 20 beautifully colored slides to illustrate this most interesting subject.

In a cross-section of the coastal plains, he showed that sedimentary deposits exist down to 40,000 feet on the shelf. The lowermost Tertiary beds are estimated to be 30,000 feet in depth. The principal structure along the Gulf Coast with which oil is associated is the salt domes. Extreme pressures existing at depths of the salt beds are sufficient to make the salt flow upward and form these domes. He showed an aerial photograph of Avery Island, an example of a salt plug that had reached the surface. It was on this island (which is surrounded by marsh) that rock salt was first found on the North American continent. The salt mass at Avery Island compares favorably in height at least but possibly not in width, with the great mountains on earth. From 190 to 200 known piercement type salt domes have been found in the Gulf Coastal area.

In discussing the continental shelf, the speaker defined this term as being that area extending outward to a depth of roughly 70 fathoms where the ocean floor slope steepens rapidly. The continental shelf of the U. S. involves approximately 277,500 square miles, that of the Gulf Coast alone consisting of 132,000 square miles. It was shown by a map of the Alaska shelf that the area involved on the continental shelf there was about 287,000 square miles.

*(Continued on Page 38)*



# Southwest Texas Section Activities

By Raymond Keller, Jr.

Election of 1950 officers was one of the main features at the November 16 meeting in Corpus Christi which was attended by 150 persons. R. C. Granberry, division petroleum engineer for Humble Oil & Refining Co. in Corpus Christi was elected chairman, D. A. Davidson, Jr., district superintendent of Pan American Production Co. in Lyford was named vice chairman and Lee J. Thronsen, district engineer for Sun Oil Co. in Corpus Christi was elected secretary-treasurer.

Directors elected from Corpus Christi were Charles H. Snelson, district production superintendent for Seaboard Oil Co.; Houston Parish, owner of Engineering Service Co.; E. C. Sargent, manager of exploration and production, Holly Development Co., and Harry Vaughn, sales engineer with Lane-Wells Co. Directors named outside of Corpus Christi: Frank H. Dotterwich, head of the petroleum engineering department, Texas A. & I. College in Kingsville; J. B. Jones, division sales manager of Halliburton Oil Well Cementing Co. in San Antonio; Austin Shook, district petroleum engineer with The Texas Co. in Alice, and George Wilson, district engineer with Magnolia Petroleum Co. in Alice.

*Performance of the Lower Pawelek Reservoir, Falls City Field, Karnes County, Texas,* was presented by John W. Crutchfield, Crutchfield & Pruett, and Emil Bowers, Southern Minerals Corp. The paper, which covered the initial results of a pressure maintenance by water return project in the reservoir, is summarized as follows:

The reservoir is an elliptical, low relief structure with sand thickness ranging from 25 to 40 feet, with producing formations as high as 5,663 feet subsea, and the original water table was established by drill stem test at 5,716 feet subsea. Subsurface geology showed a major east-west fault and closure on the south, or downthrow side, and the discovery well was completed at 4,640 feet in the Lower Bartosch Sand in December, 1944.

In the two years following discovery, 12 oil reservoirs were discovered with pays between 4,600 and 6,050 feet in the Middle and Lower Wilcox formations. So far, 64 wells have been drilled, 61 by Southern Minerals Corp., major acreage holders, two by Gulfshore Oil Co., and the other by Magnolia Petroleum Co.

Southern Minerals made the deepest test recently in a 10,235-ft. hole, which penetrated the Edwards and a portion of the Glen Rose. No commercial oil or gas production was indicated below the Lower Wilcox.

**R. C. Granberry, division petroleum engineer for Humble Oil and Refining Co. in Corpus Christi, was elected chairman of the Southwest Texas Section on November 16.**

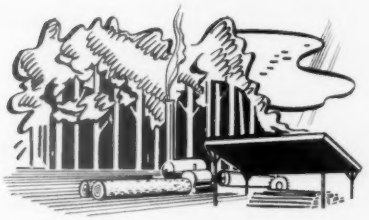
Reservoir pressure was 2,538 psi in the original well in November, 1945. It was believed that the pressure would stabilize at a high level, even as late as March, 1947, although no reservoir calculations had been made by that date. It appeared that the water influx was approaching reservoir withdrawals in magnitude, since any large differential would result in a major pressure decline because of the extremely low compressibility of the undersaturated reservoir oil. It was decided later that the limited natural water drive would not support the desired rate of oil production. Pressure had declined to 2,281, down 344 psi, by March, 1948, and five wells were on artificial lift and the majority of the remaining wells were showing lowered tubing pressure. Coupled with this problem was the fact that surface evaporation was no longer adequate for disposing of the increasing volume of salt water.

The first water was injected on March 3, 1948. Initial injection was at the rate of 500 B/D, and this was later increased to 1,800 barrels. Injection well surface pressure was from 400 to 600 pounds. After injection of 100,000 barrels, on July 1, reservoir pressure had increased to 2,345 pounds, while approximately 213,000 barrels of reservoir fluids had been withdrawn.

With a net withdrawal rate of approximately 500 B/D, pressure has increased to around 2,400 psi, and has been maintained in that vicinity. It was 2,380 psi when last measured in July, 1949. Because of the limited amount of water which can be used in the program, additional salt water disposal wells in other sands may be necessary. In later stages of the reservoir, additional injection wells will be required to provide the necessary injection capacity and proper distribution of the injected water. ★ ★ ★

# East Texas Section Activities

By Peter E. Des Jardins



### *Joint Meeting*

The semi-annual joint meeting of the Section and the Shreveport Geological Society was held at Monsour's Restaurant in Shreveport on the evening of October 25. Following dinner, H. F. Dunlap addressed the assembled group on the very timely topic of atomic energy. Dunlap, who is now associated with the Research and Development Department of the Atlantic Refining Co., was associated with Carnegie Institute in the field of military physics during the war. After presenting a brief history of the development of the present knowledge of nuclear physics, and a review of the fundamental principles of nuclear energy, Dunlap discussed possible future uses of atomic energy. He felt that in addition to the atomic bomb, nuclear energy could be used to generate steam for use in turbines. This use would be particularly adaptable to certain military craft, such as submarines, and in peace time, could provide a source of power for areas where transportation would make use of other fuels too costly. He expressed the opinion that atomic energy would have no economic advantage over other fuels as a source of power, in areas where other fuels were available in sufficient quantities. He stated that in terms of their ability to sustain the nation's power supply, the present known reserves of atomic fuel in this country are approximately equal to the oil reserves. A lively discussion of Dunlap's talk demonstrated the clarity of his presentation and the general interest in this topic.

### *Monthly Meeting*

The November meeting of the East Texas Section was held at the Kilgore Hotel on November 8. At the meeting, Chairman Jack M. Shepherd announced that the election of officers would be held at the December meeting, and appointed a Nominating Committee consisting of W. M. Jones, Chairman, R. M. Hess and John S. Bell. Jones requested that all members submit their suggestions for candidates for the various offices to the Nominating Committee.

The evening was highlighted by an address on "Pressure Maintenance of Wesson-Hogg Sand Reservoir by Water Injection", presented by Sterling Lacy, petroleum engineer with the McAlaster Fuel Oil Co. Lacy stated that this reservoir, discovered in January, 1946, by the McAlester Fuel Oil Co., was a long relatively narrow sand bar terminated upstructure by a fault and downstructure by a water level. Available information indicates an average porosity of 32 per cent, an average permeability of 2772 md, and an average thickness of 24.16 net feet of sand. Since initial gas-oil ratios were only 100:1, no free gas cap was present. The production of 689,816 barrels of oil caused a drop in reservoir pressure of 645 psi from an initial pressure of 1299 psi, indicating that no effective water drive existed, and that some form of pressure maintenance would be desirable.

*(Continued on Page 42)*

**Sterling Lacy, petroleum engineer with the McAlester Fuel Oil Co., spoke before the November 8 meeting of the East Texas Section. His topic was *"Pressure Maintenance of Wesson-Hogg Sand Reservoir by Water Injection."***

**The above picture, taken at the meeting on November 8, shows a group of regular attendants at East Texas Section meetings. L to R, R. K. Theis, chairman of the entertainment committee, Schlumberger Well Surveying Corp., Tyler; H. K. McArthur, Halliburton Oil Well Cementing Co., Kilgore; R. M. Hess, director of East Texas Section, Shell Oil Co., Kilgore; Ron Johns, oil editor of the Tyler Morning Telegraph and Courier-Times.**

# Lubbock Sub Section Activities
# Permian Basin Section

By Robert R. Shaffer

Interest in the AIME, leading to an expansion of AIME activity, advanced greatly on November 21 with a meeting in Lubbock to organize a Sub Section for the South Plains area of Texas. Robert R. Shaffer, engineering trainee with Stanolind Oil & Gas Co. in Levelland, and one of the leaders in the organizational activity, presided at the meeting.

Shaffer explained the functions of the AIME, and of the Petroleum Branch, to the group, and recommended that a Sub Section be formed at this time rather than a full Local Section. This was unanimously approved by vote. Sample bylaws were then read and discussed in order for interested persons to understand the rules governing a Sub Section, and to assist a committee in writing a set of bylaws for the new organization. It was recommended from the floor that consideration be given in June, 1950, to reorganization as a full Local Section.

Tom C. Frick, chairman of the Permian Basin Section, appointed the following committee to nominate officers and to draft bylaws for the Sub Section: Paul S. Johnston, Texas Tech, Lubbock; E. B. Armstrong, Honolulu Oil Corp., Lubbock, and Robert R. Shaffer. This committee will render its report at a meeting to be held in December. At that time an election of officers will be held and a charter will be presented to the group.

In addition to the organization business, the group heard a paper by R. M. Leibrock, district reservoir engineer with Stanolind in Lubbock, entitled *Factors to Be Considered in Determining the Feasibility of Gas Injection.* A summary of the paper, which was confined to a consideration of depletion type reservoirs, follows:

It has been a commonly accepted practice for several years to analyze the available performance data for a reservoir, and on the basis of such an analysis, to predict the future performance characteristics by the material balance method. The extension of this method, the performance of a depletion type reservoir under a dispersed gas injection program has been less generally accepted through the industry. Controversy for the most part has centered around the use of the so-called "conformance or sweep-efficiency factor" which is introduced into the material balance equation as a means of taking into account the fact that less than 100 per cent of the total reservoir will be swept by the injected gas. Performance data were presented for a San Andres Lime gas injection project which has been in operation for three and one-half years. These data, particularly the gas-oil ratio behavior, indicate that a large percentage of the reservoir is being swept by injection gas. On the basis of observed performance characteristics in this particular field, it was concluded that extension of the material balance methods, with proper modification by a reasonable sweep efficiency factor is justified in predicting the performance of a dispersed gas injection program in a depletion type reservoir.

★ ★ ★

# Kansas Section Activities

By V. J. Mercier

Nearly 70 Kansas engineers turned out October 5 at the regular monthly meeting to hear George C. Howard of the Stanolind Oil and Gas Co., Tulsa, Oklahoma, present his paper on "The Hydrafrac Process." An open discussion followed the formal presentation with S. S. S. Westbrook of the Halliburton Oil Well Cementing Co. reporting on results of commercial applications of the process.

Lewis E. Young, president of AIME, visited the Section and the University of Wichita on November 9. During the late afternoon Young spoke for a few moments to the Student Associates, then took time to meet and talk with each one individually.

The same evening Young met with the Section at their regular monthly meeting and spoke on a subject of deep concern, the nationalization of industry. The response of his audience and the newspaper stories that followed demonstrated that his message struck home.

Following Young's talk was a technical paper delivered by W. O. Keller of the Stanolind Oil and Gas Co., Tulsa, Oklahoma, entitled *Critical Analysis of the Effect of Well Density on Recovery Efficiency.* Local engineers gave Keller an active open-forum session at the conclusion of his formal presentation.

Candidates for officers and directors of the Section for the year 1950 were announced by the chairman as follows:

Chairman: W. F. Brown, Dowell, Inc.; D. H. Sholtus, Great Lakes Carbon Co.

Vice-Chairman, Wichita: H. C. Davis, Vickers Petroleum Co.; P. T. Amstutz, Jr., Amstutz & Yates, Inc.

Vice-Chairman, Western Kansas: W. R. Warren, Stanolind Oil and Gas Co.; J. C. Gallivan, Wood River Ref. Co.

Vice-Chairman, Eastern Kansas: Fred Kluck, Ohio Oil Co.; Wendell Haugh, Great Southern Oil Co.

Secretary-Treasurer: Louis Chombert, Schlumberger; Don Hellar, Sohio Petroleum Co.

Director, Wichita: Lamont E. Smith, Franco-Central Oil Co.; Lester Wilkonson, Sunflower National Gas Co.

Director, Western Kansas: Clayton Nygaard, Sohio Petroleum Co.; Herb Roberson, Dowell, Inc.

Director, Eastern Kansas: Carl Temple, Sohio Petroleum Co.; L. W. Holsapple, Sinclair Oil Co.

At a meeting of the Executive Committee of the Section, the retiring chairman, V. J. Mercier, was unanimously elected to the office of Section Delegate for the new Council of Section Delegates. Mercier will serve the Kansas Section in this capacity for two years Beginning January 1, 1950. ★ ★ ★

# Mid Continent Section Activities

By Glenn M. Stearns

The last regular monthly meeting of the Mid-Continent Section was held in Lorton Hall at Tulsa University on November 14, 1949. William D. Owsley, technical adviser of Halliburton Oil Well Cementing Co., Duncan, Oklahoma, was the featured speaker. Owsley's talk was based on a list of 45 questions concerning the practical aspects of oil well cementing. These questions had been previously submitted by various petroleum engineers who are members of the Mid-Continent Section. Various questions relating to cementing equipment, cementing technique, special admixtures and various other phases of casing cementing operations were asked.

After the prepared questions were answered the meeting was opened to discussion from the floor. It was evident from the amount and nature of questions and comments, that all of the approximately 150 engineers present enjoyed the meeting and obtained practical information for use in connection with the cementing of casing under various well conditions. Meeting arrangements were under the direction of Roy H. Smith, vice president in charge of programs. In the absence of Herbert M. Cooley, section chairman, James N. McGirl presided.

### *Study Group Activities*

The Mid-Continent Study Groups, organized in February, 1947, predict another successful round of meetings for the coming year. J. J. Arps, chairman, and A. W. Walker, Jr., co-chairman, of the Study Group activities report that the results of this year's opening meetings of the two Study Groups have exceeded all expectations with respect to both attendance and interest. Continued success is assured with C. M. Copeland and L. A. Ogden, chairman and co-chairman, respectively, as officers of the Production and Drilling Study Group and C. H. Keplinger and Kenneth R. Teis, chairman and co-chairman, respectively, as officers of the Reservoir Study Group.

On October 18, Robert G. Hamilton, consulting engineer of Tulsa, opened the Production Study Group meeting with an excellent talk on the subject, "Problems of Electric Log Interpretation in the Mid-Continent Area." Both local members and guests contributed to the success of the meeting with an interesting and intensive discussion of the subject. The Production Group is anticipating an interesting meeting on November 22 when Douglas Johnson, Johnson-Fagg Engineering Co. of Tulsa, will present a discussion of "Dynamometer Charts and Well Weighing."

E. K. Schluntz, Shell Oil Co., Tulsa, opened the first meeting of the Reservoir Study Group with the subject "Results of Repressuring in the K.M.A. Field in North Texas." His well-organized presentation of the current and historical operations, together with a review of reservoir characteristics and behavior of the various units of the K.M.A. Field resulted in a very informative discussion of both the K.M.A. Field and general reservoir engineering problems. The Reservoir Group is looking forward to their next meeting when John R. McKay, British-American Oil Co., Ltd., of Calgary, will present a discussion on "Oil Fields of Western Canada."

All Study Group meetings are held in the Engineering Building on the University of Tulsa campus at 7:30 p.m., and the Mid-Continent Section Study Groups extend a cordial invitation to all who are interested to attend their meetings and participate in the discussions. ★ ★ ★

# Oklahoma City Section Activities

By Harold Sells

Sixty members were in attendance at the November 10 meeting of the Section. Following a brief business meeting, Lincoln Elkins, section chairman, introduced the principal speaker, Milton Williams, Humble Oil and Refining Co., of Houston, Texas.

With the exception of a four-year period in the United States Navy, Williams has been in the Production Research Division of Humble since 1935. His paper, *Estimation of Interstitial Water from the Electric Log* was of special interest to all members, since a comparison was made between the water saturation determined from the analysis of actual cores and the interstitial water calculated from the resistivity curve for this same formation.

Details of the experimental data and calculations were given by slide projection. Williams' conclusion, in which he advanced the viewpoint that whenever the laboratory determined water saturations and the resistivity calculations of water saturation are in close agreement this may be due to a set of compensating errors only, evoked considerable comment and projected an interesting discussion. In answering a question regarding the details of the core analyses, Williams stated that determinations of water saturation from cores were made by several methods and results compared and correlated. One determination was made on location, and a second, or more, made in the laboratory. Special care was taken to make certain that a minimum amount of evaporation occurred before the analysis was made. Immediately upon being removed from the core barrel, the core sample was placed in a sealed can and analyzed within an average of 15 to 30 minutes afterward. Core samples were cut from the centers of the cores to minimize contamination.

This paper was previously presented at the San Antonio Branch Meeting in October and is available in the preprints of that meeting. An abstract of the paper was published in the September JOURNAL. ★ ★ ★

# North Texas Section Activities

By Kenneth F. Anderson

### *October 17 Meeting*

The October meeting of the North Texas Section was held at the Blackstone Hotel in Fort Worth, and attended by about 60 members and guests. M. M. Kinley, of the Kinley Co., Houston, Texas, who has gained world-wide fame fighting wild oil and gas wells, showed a series of motion picture films, and gave a very interesting discussion of some of his most thrilling experiences in bringing blowouts under control. A summary of this program was printed in the March issue of the JOURNAL under Southwest Texas Section Activities.

### *November 15 Meeting*

In the absence of the Section chairman, Don Harlan, Jack Crichton, vice-chairman, from Dallas, presided at the November meeting which was held at the Melrose Hotel in Dallas. Approximately 75 members and guests were present to hear an excellent discussion by William Owsley, technical adviser for the Halliburton Oil Well Cementing Co., Duncan, Okla., concerning the application of "Hydrafrac" and the results which have been obtained in the field application of this process.

After a short discussion of Sectional affairs, it was announced that the Nominating Committee to select candidates for 1950 officers of the North Texas Section has been approved by the Executive Committee, and will consist of: Charles B. Carpenter, Dallas, chairman, Gordon Fisher, Fort Worth, and Bruce Davidson, Wichita Falls. The election for the 1950 officers will be made on January 5 in Dallas at which time Lewis E. Young, president of the AIME, will be the principal speaker.

Program Chairman William E. Stiles introduced Owsley, and a summary of his talk is as follows:

It has long been realized that a means for increasing the productivity of oil-bearing reservoirs was highly desirable. As a result of research done by Stanolind Oil and Gas Co., a procedure which has come to be known as "hydrafrac", was developed that will accomplish this in many instances.

The hydrafrac process generates new and increased permeability in the bore of a well by hydraulically splitting the formation being treated. Briefly, this is done by injecting into a well crude oil, or some refined product such as kerosene, which has been rendered highly viscous by the addition of chemicals. This viscous material is pumped into the formation at a sufficiently high rate to create pressure in excess of that caused by the overburden. The gel usually has sand mixed with it that is carried into the fracture to act as a propping agent. Next, the viscous material is caused to revert to approximately its original viscosity by bringing it into contact with a breaker fluid, which is an oil containing chemicals that react on the gel. The well is allowed to remain closed until the gel is completely broken down. This usually requires about 24 hours, and then the well may be placed back on production without the necessity of cleaning out the bore.

Owsley said that confirmed production reports have been obtained on 91 wells subjected to this process as of November 1, 1949, and that from this number, 58 have shown increases in production. The process has been used most widely in Oklahoma, North and Central Texas, and the Rocky Mountain region where the formations are usually dense and hard. Any area, however, is usually adaptable to the application of hydrafrac, if the original permeability is low, but good bottom-hole pressure exists, and oil remains in place.

Owsley added that hydrafrac is not to be considered as a "cure all" and that it certainly cannot produce oil from a formation in which producible oil is not present; however, whenever conditions are evaluated properly before undertaking such treatment, it is possible to say with considerable accuracy whether or not production can be increased by its application. ★ ★ ★

# Mississippi Sub Section Activities

By Sam J. Poythress, Jr.

The first combined business and social meeting of the Sub-Section was held December 3 at the Brookhaven, Mississippi, Country Club.

The feature of the evening was dancing from 8 'til 12 to the music of Dick Wright and his orchestra, so that members and their wives, etc., would have an opportunity to get better acquainted. At intermission a buffet of turkey and all the trimmings was served.

Jack Johnson, Sun Oil Co., Brookhaven, was program chairman.

The meeting was opened with a short business session, the important item of business being the election of Sub-Section officers for 1950. This election will be reported in a later issue of the JOURNAL. ★ ★ ★

## Gulf Coast Section

*(Continued from Page 33)*

The shelf in the Gulf Coast is 50 miles wide at the Rio Grande; 140 miles wide off Southwest Louisiana, and 50 miles off Mobile, Alabama. Discussing the origin of the shelf, Carsey said that much study has been devoted to this subject, but no completely satisfactory explanation of this occurrence can be given. He felt that possibly an answer could be found by borrowing from several authors. If the waters had been lowered roughly 70 fathoms rather than 300 feet during the Pleistocene ice age, this would help account for the world-wide continental shelf. The 70-fathom depth would correspond with Fisk's and Shepard's findings, Carsey reported.

The speaker revealed that 164 topographic features are to be found on the continental shelf. A concentration of these features is to be found near the 70-fathom depth. He discussed the political boundaries claimed by the coastal states. Remarking about the significance of the shelf, Carsey said, "Experience has already shown that there is considerable question as to whether or not production in the open waters will prove profitable. Certainly, only the best of the structures may prove of value." ★ ★ ★

## STUDENT ACTIVITIES, OKLAHOMA UNIVERSITY

By Bob True and J. W. Tucker

### *Petroleum Engineers Club*

Kenneth B. Barnes, engineering editor of The Oil and Gas Journal, was guest speaker for the November 3 meeting, with a paper on the oil business in South America. He discussed in detail the methods of drilling, production, and transportation in these countries and used slides to fully explain the oil reservoirs and their structures in the important fields.

Lloyd E. Elkins, director of production research for Stanolind Oil & Gas Co., and chairman of the Petroleum Branch, spoke to the club November 22 on the value of a petroleum engineering education. Elkins stated that the petroleum graduate of the present time faces more barriers of competition than the graduate of ten years ago faced, caused by the increasing number of petroleum engineers. He explained the value of a college education to an individual in the improvement of knowledge, in the ability to reason and express himself, and in personality development. He warned the students to not confine themselves to one professional phase alone, and to pay close attention to the practice of wholesome human relations.

### *Pi Epsilon Tau*

The growth of this honorary petroleum engineering fraternity is advancing rapidly with three chapters now operating and others planned. The original Alpha chapter was established on the Oklahoma University campus in November, 1947, the Beta chapter at Tulsa University in the spring of 1949, and the Gamma chapter at Texas Tech in November, 1949. Chapters are now being organized at Louisiana State University, the University of Southern California and the University of California.

Officers of the Alpha chapter for the fall semester of this year are Spencer L. Taylor, president; Henry G. McKaskle and James W. Tucker, vice presidents; John Sanders and Earl G. Thurman, secretaries, and Ernest J. Dickinson, St. Pat's Council representative.

J. H. Field, chief mechanical engineer for Sohio Petroleum Co. in Oklahoma City, spoke at the October meeting, at which 49 new members were initiated, on the subject, "Engineers as Salesmen."

Henry L. Waszkowski, division petroleum engineer for Magnolia Petroleum Co. in Oklahoma City, and vice-chairman of the Oklahoma City Local Section of AIME, was guest speaker for the November 16 meeting. He presented a paper entitled "Petroleum Conservation and Conservation Laws" written by D. V. Carter, chief petroleum engineer of Magnolia. ★ ★ ★

**Kenneth B. Barnes speaking to the P. E. Club on November 3. A P. E. graduate of O. U., he has spent several years in teaching, in petroleum engineering, and has been with The Oil & Gas Journal for the past four years.**

## PETROLEUM ENGINEERING CLUB, TEXAS A. & M.

By Paul D. McElroy

J. E. Brantly, president of Drilling and Exploration Co., spoke to the club at the November meeting on oil operations in foreign countries, dealing principally with South America, Canada, Europe and Asia. He pointed out that practically all of the oil fields in the world have been developed by Americans, and added that drilling a well overseas is much different from drilling here in the United States. Overseas a driller may be called upon to run his own cement, maintain his own roads, haul his own equipment and secure transportation for the oil he produces.

In speaking about the petroleum engineer in foreign service, Brantly cautioned that overseas work is the only type of service in which some can be satisfied, while for others it is not at all agreeable. The ratio of those who like it to those who don't is about 50-50. ★ ★ ★

## THE UNIVERSITY OF TEXAS STUDENT ASSOCIATE CHAPTER

By William F. Nicodemus

Ernest O. Thompson, a member of the Texas Railroad Commission, spoke to the Chapter November 14 on the necessity of clear, technical testimony in administrative processes. Thompson stated that the petroleum engineer should be concerned with five basic points in the presentation of testimony before administrative bodies. He said the engineer should (1) testify only on subjects he is personally informed about; (2) keep his engineering testimony on a professional basis; (3) use charts and graphs to help convey information; (4) make presentation in simple terms; (5) give only testimony that pertains to the points in question. ★ ★ ★

# Professional Services

*This space available only to AIME members. Rates upon request.*

**AMSTUTZ AND YATES, INC.**
*Consulting Petroleum Engineers*
Valuations
Reservoir Analyses
Geologic Investigations
406 KFH BLDG., WICHITA 2, KANSAS

**CARLTON BEAL**
*Consulting Petroleum Engineer*
11699 BELLAGIO ROAD
LOS ANGELES 24, CALIFORNIA
Phone: ARizona 74294

**FRANK N. BOSCO**
PETROLEUM ENGINEERING
*Exploration — Evaluation — Operation*
838 Symes Building — *By Appointment Only*
PHONE: TABOR 7361 — DENVER, COLO.

**JOHN G. CAMPBELL, CHEMIST**
*Field Charcoal & Podbielniak Analyses*
*Waters — Oil Field Brines — Cores*
422 N. Lower Broadway, Corpus Christi, Texas

**PAUL CHARRIN**
*Consulting Engineer*
ATLAS WELL SERVICE CORPORATION
UNIVERSAL EXPLORATION COMPANY
913 Union National Bank Building
HOUSTON 2, TEXAS
Phone: Preston 0060

**ALEXANDER M. CROWELL**
*Natural Gas Consultant*
So. Arkansas — LOUISIANA — Coastal Texas
NEW ORLEANS — SHREVEPORT
1415 Carondelet Bldg. — 3746 Richmond Ave.
Phone: Raymond 3861 — Phone: 8-1419

**CRUTCHFIELD AND PRUETT**
CONSULTING PETROLEUM ENGINEERS
224 Wilson Building
CORPUS CHRISTI, TEXAS
*John W. Crutchfield* — *Horton T. Pruett*

**DENTON-SPENCER COMPANY, LTD.**
CONSULTING PETROLEUM ENGINEERS
Lancaster Bldg. — Calgary, Alberta

**ALEXANDER DEUSSEN**
*Consulting Geologist and Petroleum Engineer*
Room 413, Commerce Bldg. Addition
HOUSTON 2, TEXAS

**EARLOUGHER ENGINEERING**
*Petroleum Consultants - Core Analyses*
Specializing in Secondary Recovery
Investigations - Appraisals - Operations
311-319 East Fourth Street
TULSA 3, OKLAHOMA
Office 2-5129 — Laboratory 2-6139

**FARIS & WARREN**
*Consulting Petroleum Engineers*
McClintic Building
MIDLAND, TEXAS
Production & Reservoir Engineering
Evaluations — Development

**HERSHAL C. FERGUSON**
*Consulting Geologist and Paleontologist*
Esperson Building
HOUSTON, TEXAS
825½ Gravier Street — New Orleans, La.

**FITTING, FITTING & JONES**
*Engineering & Geological Consultants*
Petroleum — Natural Gas
Box 1299
PERMIAN BLDG. — MIDLAND, TEXAS

**WILLIAM HURST**
*Petroleum Consultant*
Reservoir Engineering - Primary & Secondary Recovery, Gas Cycling, Evaluations
6445 BROMPTON ROAD
Madison 1181
HOUSTON, TEXAS

**MICHEL T. HALBOUTY**
CONSULTING GEOLOGIST
AND PETROLEUM ENGINEER
Shell Building
Houston 2, Texas — Phone P-6376

**NORRIS JOHNSTON**
**N. van WINGEN**
PETROLEUM TECHNOLOGISTS, INC.
*Production Research — Core Analysis*
*Reservoir Engineering*
868 TRUCKWAY, MONTEBELLO, CALIFORNIA
PHONE: UNION 1-5338

**H. L. KIRKPATRICK**
CONSULTING PETROLEUM ENGINEER
*Property Management - Well Completions*
Proration - Reports - Appraisals
*445 Delaware Avenue*
SHREVEPORT, LA. — PHONE 7-8295

**W. T. MENDELL**
*Engineering & Geological Consultant*
Second National Bank Building — Houston, Texas
CApital 7612

**CHARLES GILL MORGAN**
*Geologist*
805 Mercantile Securities Building
DALLAS, TEXAS — PHONE CENTRAL 7963
*Specializing in Structural Geology and Problems Related to the Exploration for Petroleum. Confidential Reports.*

**CLEVELAND O. MOSS**
CONSULTING PETROLEUM ENGINEER
Estimates of Oil and Gas Reserves
Valuation—Production Problems—Proration
208 MIDCO BLDG. — TULSA 3, OKLA.

**ERNEST K. PARKS**
CONSULTING PETROLEUM ENGINEER
Planning, Direction and Examination of Oilfield Operations, Estimates of Oil and Gas Reserves, Oil Property Valuation
614 S. HOPE STREET, LOS ANGELES, CALIF.
Telephone: VanDyke 4659

**HARRY H. POWER**
*Consulting Petroleum and Chemical Engineer*
*Production, Reservoir, Valuation and Development Engineering*
P. O. Box 1542 — University Station
AUSTIN, TEXAS

**A. L. SELIG**
*Consulting Petroleum Geologist*
GULF BUILDING — HOUSTON, TEXAS

**S. FRED SHAW**
*Gas Lift Specialist*
301 Terrell Road, Phone: T-9754
SAN ANTONIO, TEXAS

**WM. H. SPICE, JR.**
*Consulting Geologist*
2101-03 Alamo National Building
SAN ANTONIO 5, TEXAS

**JOSEPH B. UMPLEBY**
Geologist and Engineer
*Office Consultation Only*
5945 LUTHER LANE
DALLAS 5, TEXAS

HARRY C. SPOOR, JR.
Consulting Geologist
Petroleum . . . . . Natural Gas
COMMERCE BLDG. HOUSTON, TEXAS

HAROLD VANCE
CONSULTING PETROLEUM ENGINEER
Pet. Engr. Dept. A & M College
College Station, Texas

BASIL B. ZAVOICO
Petroleum Geologist and Engineer
220 E. 42nd St. City National Bank Bldg.
New York 17, N. Y. Houston, Texas
MUrray Hill 7-7591 Charter 4-6923

## San Joaquin Valley Section

*(Continued from Page 27)*

presence of permeability. In some instance, the potential curve may be used to locate the oil-water interface in a thick sand.

### The Microlog

The microlog is an electrode system of very short spacing. The electrodes are set in an insulating rubber pad and pressed to the wall of the hole by springs.

This system eliminates "Hole Effect" and "Bed Thickness Effect" but the "Invasion Effect" is still present.

The possible uses of the microlog are in determining the presence of very thin strata, in obtaining very accurate sand counts and in locating permeable strata. The determination of permeable zones has already been a success in some areas.

### Induction Logging

Induction logging is a system designed to overcome the difficulties of logging with wall scratching electrodes, used in oil and oil-base muds.

Electric currents are induced in the formation by an induction coil and the magnetic flux generated by this current is detected by a pick-up coil. The galvanometer defections are proportional to conductivity and not to resistivity. The device thus reads in a reciprocal fashion to the usual resistivity logging device.

Some difficulty has been encountered in obtaining electronic stability and no curve comparable to the usual potential curve is obtained.

### Advantages of the Electric Log

1. The electric log is a continuous picture of the entire open hole. There is no lost recovery.

2. The electric logging service is relatively inexpensive compared to other formation evaluation methods.

3. The electric logging of an interval consumes considerably less rig time than coring the same interval, and therefore costs much less.

4. The electric log has a wide variety of uses, such as obtaining a sand count, locating water, estimating the relative fluid content, determining optimum points at which to set casing, correlating with other logs, determining the thickening and thinning of various strata, locating sidetracked fish, and in checking the casing shoe depth. The electric log is also used in reservoir studies to estimate the magnitude of reserves.

### Disadvantages of the Electric Log

1. Resistivity is not only a function of oil saturation. A "kick" on the electric log may indicate the presence of oil or gas, non-porous formation, fresh water sand, or a seriously invaded interval.

2. The information obtained by the electric log is not concurrently obtained with the progress of the drill bit. The information obtained by coring or by mud logging on the other hand, is almost concurrently obtained with the progress of the drill bit, which allows testing in an opportune manner and at an opportune time.

### Discussion

In the discussion period following the talk, a question was asked regarding the reliability of the electric log in determining the presence of oil, water, or gas. Walstrom stated that the question could only be answered by dividing it into two parts. For development wells in salt-water bearing formations the accuracy should be 75 per cent. In fresh-water formations it would be more nearly 50 per cent.

For exploratory wells the use of the electric log alone results in very low accuracy. In this type well the log should be supplemented in every possible way, (i.e., cores, ditch samples, rate of penetration data, formation test, etc.). ★ ★ ★

## Delta Section

*(Continued from Page 31)*

water drilling offshore. He indicated that a great deal of research and development must yet be done before the ideal solutions to these problems are found. J. W. Winfrey, senior engineer in charge of offshore research for Humble Oil and Refining Co. in Houston stated that his department is now working on the following research problems: (1) analysis of wave forces—horizontal and vertical; (2) portable drilling platform; (3) personnel transfer at offshore locations and (4) moorings. ★ ★

### Hallowe'en Dance

The first annual Delta Section Hallowe'en Dance was held on the night of October 28, at Metairie Country Club. E. N. VanDuzee, Shell Oil Co., was in charge of arrangements and much favorable comment was heard from the large crowd.

Intermission entertainment was provided by Delta Section personnel led by J. W. Watson, Schlumberger Co., as Dr. Zotz, a vendor of a top-notch patent medicine. Watson was ably assisted by a large "quartet" composed of R. S. Sullins, Humble Oil and Ref. Co., J. R. Gregson, Rey Supply Co., R. B. Kelly, S. W. Richardson, Duane Schmeckle, Howard Shatto, Shell Oil Co., William Shelton, Humble Oil and Refining Co., and Harry Loehr, Baroid Co. ★ ★ ★

## East Texas Section

*(Continued from Page 35)*

Operators began meeting in August, 1947, to discuss unitization for pressure maintenance. James A. Lewis, an independent petroleum engineer was hired to make a study of the reservoir and determine whether gas or water would be the most efficient and economical flooding medium. Lewis reported that a recovery of 378 barrels per acre foot could be expected from natural depletion, gas injection would increase recovery to 800 barrels per acre foot, while water injection should recover 1000 barrels per acre foot.

On July 1, 1948, unit operation became effective with 100 per cent of the owners of working interests and approximately 77 per cent of the royalty owners having signed the unitization and pressure maintenance agreement and the royalty pooling agreement.

The Nacatoch horizon which occurs in this area at approximately 1500 feet provided an adequate source of salt water for the flooding medium. Water injection began in September, 1948, and by August, 1949, 7736 barrels of water per day were being injected. Oil production during August averaged 4857 barrels per day were being injected. Oil production during August averaged 4857 barrels per day. Water injection in excess of reservoir withdrawals will be maintained to increase the bottom hole pressure to 1500 psi, and return the producing wells to natural flow.

Lacy stated that after reservoir pressure had declined below 700 psi, an increase in gas-oil ratios was observed in the highest structural wells and it was thought that gas was breaking out of solution from the oil. Analysis of a bottom hole sample revealed that the saturation pressure for the crude was 364 psi. The reservoir pressure has never declined to that point. It was discovered that the James lime was thrown opposite the Hogg sand by the fault on the upstructure end of the reservoir. The James lime had been tested in wells near the fault and found to contain a high pressure gas. It is now assumed that extraneous gas was entering the reservoir through the fault plane. Additional migration of gas into the Hogg sand reservoir has been blocked by injection of salt water into wells near the fault plane. Entrance of extraneous gas into the reservoir served to retard the rapid decline in bottom hole pressure, but it is felt to be harmful to the reservoir in the light of water flooding. The gas has now created a partial gas cap in certain areas and is retarding the fast buildup in bottom hole pressure expected from water injection. The major harm expected from the gas is water channeling due to the difference in relative permeabilities of oil and gas to water.

Water injection halted the bottom hole pressure decline in January, 1949, after it had reached a low of 412 psi. As of September 30, 1949, injection of 2,374,943 barrels of salt water had increased the arithmetical average bottom hole pressure a total of 65 psi.

Lacy pointed out that individual wells have definitely displayed beneficial effects of water injection, with increases in oil production of as much as 92.4 per cent.

Considerable discussion followed Lacy's address, with particular emphasis being placed on the legal aspects of unitization in the State of Arkansas. Chairman Jack Shepherd expressed the appreciation of the Section for Lacy's very thorough presentation of the problems involved in a waterflood project, and expressed the Section's interest in an additional address when flooding of the Hogg sand is more nearly completed. ★ ★ ★

# Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 601 Continental Building, Dallas 1. Show return address on envelope. These replies will be forwarded unopened, and no fees are involved.

Replies to the positions coded Y-2524 and Y-2415C below should be addressed to: Engineering Societies Personnel Service, 8 West 40th Street, New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

### PERSONNEL

♦ Graduate geologist, 25, married, wants position anywhere in or out of the United States, salary open. Code 112.

♦ Petroleum-mechanical engineer and executive. Graduated University of Oklahoma, 1929, B. Sc. in P. E. Have 16 years production and drilling experience with major company, including 4 years specification supervision on all types of drilling and production equipment. Also 4 years engineering administrative experience as executive in oil tool manufacturing company. Registered professional engineer. Married, two children. Desire drilling and/or production supervisory post for independent company or engineering executive position with service or equipment company. Code 113.

♦ Geologist, with three years' experience in stratigraphy and micropaleontology, B.A. degree and one year of graduate study, available January 1. Code 114.

♦ Petroleum engineer, B.Sc. in 1940, age 30, single. Nine years' experience in petroleum - production engineering, principally conservation and proration practices; industrial engineering; and mineral economics, preparation and editing of mineral-industry and resources surveys. Code 115.

### POSITIONS

♦ Stratigrapher. Must have a Ph.D. and be chiefly interested in Paleozoic stratigraphy and paleontology and capable of teaching sedimentation. Salary up to $4,500 for nine months depending on experience. Location, Missouri. Y-2524.

♦ Assistant or associate professor with industrial experience in petroleum production engineering, to teach petroleum production courses. Salary open, depending on qualifications. Location, South. Y-2415C.

# aime NEWS

## ECPD Holds Annual Meeting

Engineers' Council for Professional Development held its annual meeting this year in Chicago, with a record attendance of about 150, not including a sprinkling of ladies. The Council is a joint body of the four Founder Engineering Societies (AIME, ASME, ASCE, AIEE) and the American Institute of Chemical Engineers, the American Society for Engineering Education, the National Council of State Boards of Engineering Examiners, and the Engineering Institute of Canada. Headquarters were at the Edgewater Beach Hotel, and sessions were held on Friday afternoon, Oct. 28, and Saturday morning, with adjournment following shortly after the luncheon on Saturday. Chairman Parker made his annual report at the dinner on Friday, followed by a talk by Robert E. Wilson on "The Attitude of Management Toward Research." Friday morning was devoted to an executive session of the Council at which accrediting was discussed.

Inspection and accrediting of engineering curricula continues the most notable achievement of ECPD. During the past year, delegatory committees visited 74 colleges and universities, with 64 inspections of new curricula and 250 reinspections of curricula previously accredited. Only 39 schools remain to be inspected in the immediate postwar program, according to the report of H. T. Heald, chairman of the Committee on Engineering Schools. Newly accredited engineering curricula in the field of the AIME were: University of Alabama, metallurgical; Colorado School of Mines, petroleum (production and refining); Illinois Institute of Technology, metallurgical; University of Kansas, petroleum; University of Pennsylvania, metallurgical; Princeton University, geological; Rutgers University, ceramic; A&M College of Texas, geological.

Further additions have also been made to the accreditation of curricula of the "technical institute" type, curricula in seventeen such institutions now having been approved.

Ole Singstad, chairman of the Committee on Professional Recognition, reported that the qualifications for proposed uniform grades of membership in engineering societies had been formulated. These were accepted by ECPD at the meeting and are being submitted to the various societies with the hope of acceptance. Three grades of membership are recommended: Member, Associate Member, and Student Member; with the two optional grades of Fellow and Affiliate, if desired.

The Committee on Student Selection and Guidance and the Committee on Professional Training reported studies under way. The Committee on Principles of Engineering Ethics, represented by Wm. F. Ryan, vice-chairman, reported that the "Canons of Ethics" had been adopted during the year by the Engineering Institute of Canada, and that 56 societies, with a combined unduplicated membership of well over 100,000 engineers, had now adopted the Canons, with endorsement by fifteen others. Of the leading societies, he reported that only AIME had taken no action, but this was remedied at the AIME Board meeting on Nov. 16, when AIME also approved the Canons. It is planned to publish them in the forthcoming Directory.

During the year ending Sept. 30, 1949, ECPD had an income of $37,722 of which $20,650 came from school inspection fees, $12,287 in the form of grants from sponsoring organizations, and $4,676 from publication sales. Expenses were $36,535, of which the activities of the Committee on Engineering Schools (the accrediting agency) spent $18,608, and the Committee on Information (for reports and reprints) $1,796. Cost of other publications was $8,051, and salaries, rent, and office expense totaled $7,846. An office, under the direction of Miss Elsie Murray, is maintained on the 14th floor of the Engineering Societies Building in New York.

Officers for the coming year, elected at the annual meeting, are: Chairman, H. S. Rogers, president of the Polytechnic Institute of Brooklyn; Vice-Chairman, L. F. Grant, associate professor, Queens University, Kingston, Ont.; Secretary, C. E. Davies, secretary, ASME; and Assistant Secretary, W. N. Carey, secretary, ASCE. The Executive Committee consists of the foregoing, plus V. T. Boughton, C. E. Lawall, J. W. Parker, E. W. Davis, L. F. Grant, C. G. Kirkbride, H. T. Heald, and C. S. Crouse.

## AIME Annual Business Meeting

Notice is hereby given that the Annual Business Meeting of the AIME will be held at the Hotel Statler, New York City, at 4:00 p.m., Monday, February 13, 1950, instead of on the third Tuesday in February, as provided in the bylaws.

An executive session of the incoming Board of Directors will be held immediately following the Annual Business Meeting.

## AIME Dues Payable January 1

Pursuant to Article II, Section 2, of the Bylaws of the AIME, notice is hereby given that dues for the year 1950 are due on January 1 as follows:

| | |
|---|---|
| Members | $20.00 |
| Associate Members | 20.00 |
| Junior Members for the first six years of Junior Membership | 12.00 |
| Junior Members, thereafter | 17.00 |
| Student Associates, including an annual subscription to a journal | 4.50 |
| Student Associates, without journal subscription | 2.00 |

Bills for dues were sent during October and November to members of the Metals and Petroleum Branches, and will be sent in December to members of the Mining Branch. Payment upon receipt of bill will be appreciated and will assure a prompt receipt of the journals upon publication in 1950.

# AIME
# Annual Meeting

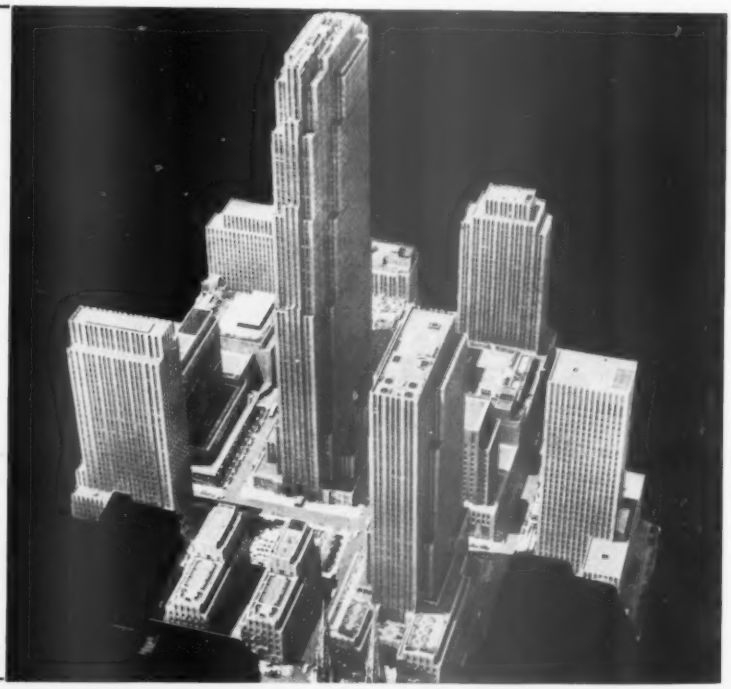
A new high in the number and variety of technical papers, a greater number of technical sessions, and bigger and better things in the field of entertainment—all are forecast for the big AIME Annual Meeting, to be held February 12-16 in New York's Hotel Statler. Each of the ten Divisions of the Institute is planning one or more sessions, and six or eight concurrent sessions are likely to be the rule.

**Local Section** activities will receive particular attention when the Institute gathers, and Delegates will have ample opportunity to discuss Section functions with the Board of Directors. A Council of Section Delegates will gather on Saturday morning, Feb. 11, for an all-day session. The following day, Sunday, Section Delegates will meet with the Board of Directors in the morning, with discussions continuing through the afternoon if necessary. The educators will hold their customary sessions on Sunday afternoon and evening. All of these pre-Meeting conclaves are designed to avoid conflict with the technical sessions.

**General Dwight D. Eisenhower,** president of Columbia University, will be the featured speaker at a "Welcoming Luncheon" which will officially open the Meeting on Monday. The man who led our fighting forces to ultimate victory, and who now heads one of the world's largest educational institutions, will doubtless have an important message for the AIME Members who are helping to engineer the peace.

**The Annual Business Meeting** of the Institute will also be held the first day of the week-long gathering. Every AIME Member is cordially invited to that meeting. The incoming Board of Directors will meet in executive session that evening, while the rest of those attending will start to partake of New York's fabulous entertainment facilities. Cocktail parties, a dinner-smoker, and radio and theatre parties will be arranged in advance by diligent members of the Entertainment Committee. Visits to the Metropolitan Museum of Art and to United Nations headquarters have been arranged for the ladies' afternoon pleasure.

**Many noteworthy sessions** are being planned to attract Members' attention at the Hotel Statler.



*New York's gleaming, skyscraping Rockefeller Center, city within a city housing everything from golf schools to consulates. Meeting delegates will find everything here to interest and amuse them when they're not busy attending technical sessions in February.*

*Record-breaking array of sessions, papers, forecast for the big February meeting in New York. Bring your problems to numerous symposiums and seminars. Eisenhower to deliver keynote address. Special attention to Local Section activities planned. Bermuda cruise an added feature for post-meeting relaxation.*

*General Dwight D. Eisenhower, president of Columbia University, who will address the Welcoming Luncheon.*

The Minerals Beneficiation Division will sponsor a symposium on mill management during the week, and it is hoped that mill operators will bring their knotty problems and hard-won solutions to be aired for the benefit of all concerned. The Institute of Metals Division will have a particularly active program, beginning its meetings on Sunday, Feb. 12, and continuing with sessions during Monday, Tuesday, Wednesday and Thursday. The Extractive Metallurgy Division has scheduled seven sessions for the week, among which will be a symposium on fume and dust collection. The usual Student Forum will be held by the Mineral Industry Education Division, and is tentatively scheduled for Monday morning. One of the high lights of the Petroleum Branch program will be a seminar on economics, production technology, and personnel problems.

**Social Events.** On Tuesday, following the opening of technical sessions, social life will also begin in earnest, leading off with a luncheon and fashion show for the women in attendance. That evening is earmarked for an informal dance, but some members may wish to take advantage of the surprising number of tickets which have been secured for the hit show "South Pacific." The gala social event of the week will, of course, be the Annual Banquet, scheduled for Wednesday night. Mining companies will be more than usually liberal in supplying favors at the social functions this year. The M. A. Hanna Co. will provide the souvenirs at the Welcoming Luncheon, the American Zinc, Lead and Smelting Co. at the Smoker, and the American Smelting and Refining Co. at the Annual Banquet.

Petroleum men, the married ones that is, will not go unescorted to their Annual Dinner this year. In an unusual move, the committee in charge has elected to invite the ladies to this function.

**Cruise to Bermuda.** A nautical return to prewar meeting pleasures will be offered this year in the form of a post-meeting cruise to Bermuda. The six day trip will include 2½ days on the island and 3½ days on the luxurious "Queen of Bermuda." The all-inclusive cost will be about $180, or more if more elaborate shipboard accommodations are desired. Members and their families will thus have an opportunity to take and enjoy with congenial friends in the profession what is perhaps the most attractive short winter cruise out of New York. Leon V. Arnold, 36 Washington Square West, New York 11, N. Y., will gladly provide further information to those interested. **Write before Dec. 31.**

A meeting announcement, with a blank for reservations for the social events, will be mailed early in January. Members can assure themselves of tickets for the events of their choice with a minimum of inconvenience by returning the reservation cards with checks. Tickets will then be mailed up to Feb. 1, thereafter they will be held at the registration desk.

**More details** will appear in the January issues of the journals. Suffice it to say here that this will be the opportunity of the year to meet old friends in the profession and make new ones, to hear of the latest in technical progress in the mineral industry field, and what is perhaps most important, to meet informally, in just one trip, dozens of the people you would otherwise have to travel all over the country to see. In private conversation you can get the low-down on many points that never appear in print. Many boast that they have come to many Annual Meetings but have never attended a Technical Session—too much to learn outside the door! And outside of the hotel, New York has several legitimate theatres, a few movie palaces, a sports arena, an occasional night club, and on Fifth Avenue and Broadway some good stores. So give yourself a winter vacation and bring along your sweetheart or wife because this will be your last chance until 1952.

# AIME Medalists for 1950

Walter H. Aldridge

Walter Hull Aldridge, president of the Texas Gulf Sulphur Co., was the guest of honor at a gala dinner at the University Club, New York City, on Nov. 16 on which occasion he was given the John Fritz Medal for 1950. The medal is customarily rotated annually between the AIME, ASME, ASCE, and AIEE, and is given for notable scientific or industrial achievement. Mr. Aldridge was cited "as engineer of mines and statesman of industry who, by his rare technical and administrative skills, has importantly augmented the mineral production of our country and Canada, and who, by giving unselfishly of his wisdom and vision, has guided his professional colleagues to higher achievements."

L. E. Young, President of the AIME, presided at the dinner, and introduced Louis S. Cates, chairman of the John Fritz Medal Board, who told of the history and purpose of the medal. John R. Suman, substituting for Cornelius F. Kelley, who had suddenly been called to Montana because of the death of James R. Hobbins, told in his own inimitable way of the career and achievements of the medalist. Harvey S. Mudd presented the medal and certificate, which was gracefully accepted by Mr. Aldridge. In his acceptance speech he was most optimistic of the possibility of finding new ore bodies to supply the mineral wants of the United States, and of devising improved techniques for discovery and treatment. He said in part: "I believe that exploitable deposits in the world are far larger than many students of the subject seem to think. Mining engineers, with the indispensable help of physicists and engineers in other branches of the profession, will find these deposits and deliver the products to industrial users in such quantities as may be required. To doubt this is to underestimate the ability of the members of the great engineering profession."

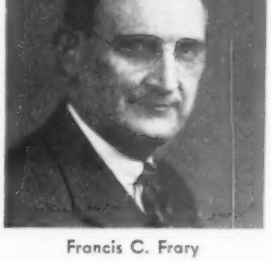
Dr. Young closed the evening by reading numerous telegrams and letters that had been received, and called upon several of Dr. Aldridge's friends for informal remarks. Those responding included Norman B. Holter, John M. Lovejoy, E. De Golyer, Henry Krumb, Herbert E. Treichler, Herbert G. Moulton, Charles A. Wight, J. T. Kilbreth, H. O. C. Ingraham, and H. L. Smith. Erle Daveler handled the arrangements for the party.

A total of 77 had sent in their acceptances and every one was there. Besides those already mentioned, AIME members present included: E. G. Bailey, W. E. Wrather, D. H. McLaughlin, H. E. Dodge, A. J. McNab, H. K. Masters, A. L. Walker, Jr., F. E. Wormser, A. G. Wolf, R. F. Bacon, Clyde Williams, F. A. Ayer, S. H. Dolbear, E. C. Meagher, J. K. McCabe, M. L. McCormack, W. T. Lundy, J. H. R. Arms, H. DeWitt Smith, D. B. Gillies, L. E. Elkins, A. B. Kinzel, P. D. Merica, Bradley Stoughton, Wilber Judson, O. B. J. Fraser, J. F. Thompson, E. R. Weidlein, C. V. Millikan, H. R. Wemple, M. B. Gentry, Philip Kraft, J. C. Kinnear, R. H. Sales, T. B Counselman, S. J. Swainson, and E. H. Robie. Also in attendance were friends of the Guest of Honor from among many in professions other than engineering.

F. H. Brownell

Charles F. Rand Memorial Medal to F. H. Brownell, "For sound leadership in the administration of nonferrous mining and metallurgical enterprises and for outstanding contributions to society in financial and legal matters relating to the nonferrous metal industry."

James Douglas Metallurgical Medal to Francis C. Frary, "For distinguished achievement in science and contribution to society by broadening the field of knowledge in all phases of the aluminum industry, and for his notable success in directing a vast research project in this industry."



Francis C. Frary

William L. Saunders Mining Medal to Howard N. Eavenson, "For the leadership he has contributed to the mining profession, and particularly for his engineering skill in design, construction and installation of productive facilities for the coal mining industry, coupled with his inspirational aid to other research and his thorough and expressed knowledge of the economic problems of the coal industry."

Anthony F. Lucas Petroleum Medal to William E. Wrather, for his untiring leadership in guiding and developing the science of petroleum geology, for reducing this science to effective application in practice, and for the inspiration he has given to others in the profession by his dedication to public service."

H. N. Eavenson

Other medalists and award winners, with their pictures and citations, will be included in a later issue of the journals, probably in the January 1950 number; Erskine Ramsay Coal Medal to Paul Weir; R. H. Richards Award to A. F. Taggart; Rossiter W. Raymond Memorial Award to Walter R. Hibbard; Robert W. Hunt Silver Medal to John S. Marsh; Metals Division Annual Award to M. Cohen and W. J. Harris, Jr.

William E. Wrather

# Information and Advice to Members of the AIME Nominating Committee

**Resolution Adopted by the Board of Directors on April 17, 1936 and Amended on May 21, 1947 and Nov. 16, 1949.**

Recognizing the fact that the problems of the committee named by the Board to prepare the "official ticket" for officers and Directors of the Institute are various and difficult; and desiring to assist this committee by setting forth some of the principles that should guide the committee and some of the qualifications that should be required of candidates, the following suggestions are formulated and the Secretary is directed to publish them in the monthly journals concurrently with the publication of the names of each newly appointed Nominating Committee and to send a copy to each member of the Committee.

**Nominations to Be Made.** Each year nine Directors are nominated. One of these nine Directors serves as President for one year, then two years as Past President, and two serve as Vice-Presidents for their entire term of three years. It is the duty of the Nominating Committee to nominate eight Directors including those who are to serve as President and Vice-Presidents. The ninth Director is nominated by the Board of Directors.

In the event that a nominee for President or Vice-President is already a Director, whose term will not have expired when he takes his new office, it will be the duty of the Board in accordance with Article VI, Section 3 of the Bylaws to elect a successor to fill his unexpired term as Director. The Nominating Committee need therefore give no consideration to this question in case their nominee for one of these offices is already a Director. A Director may be nominated to succeed himself.

**Geographical Distribution.** The Bylaws provide that "the Nominating Committee shall, so far as practicable, distribute the representation on the Board geographically." To assist the Nominating Committee in carrying out this provision of the Bylaws and to encourage, so far as will not conflict with other necessary considerations, a consistent basis for such distribution from year to year, the United States, Canada, and Mexico have been divided into fifteen districts, as shown on the official map. (See page 66, 1948 Directory.) On the basis of number of members, Districts 1, 5, 6, 11, 12, 13, 14, and 15 would be entitled to one Directorship each; District 2, three Directorships; District 3, eight Directorships; 4 and 10, two Directorships each; and Districts 7, 8, and 9, two Directorships between them. This leaves two Directorships at large.

Attention is called to the fact that many Institute members now resident in New York formerly lived in the West, South, or North and still have intimate business connections that compel them to visit various parts of the country periodically. Suitable choice of such candidates may assist the Committee in attaining a well-balanced geographical distribution. Such men are particularly valuable as Directors and their nomination and election tends to minimize the objection that a large number of Directors reside in New York.

**Consultation with Local Sections.** In order that the members residing in a District may be given an opportunity to express preference as to their representative or representatives, the Nominating Committee should invite the Local Sections in each District to suggest candidates for the consideration of the Committee. While the Committee may not always find it practical to nominate a person so proposed, such endorsement should be given primary consideration by the Nominating Committee.

**Distribution as to Major Interest.** In addition to geographical distribution of Directorships it is highly desirable that the Board should include representatives of all the various phases of Institute activity. Each of the technical Divisions is entitled to representation by one or two Directors whose major interest is in its field, and so far as practicable and consistent with other considerations, such representation should be proportional numerically to the membership in these Divisions. With the same end in view, it is desirable that the Directors should represent diverse fields, for example, geology, iron mining, nonferrous metallurgy, economics, and ore dressing. In seeking to maintain appropriate technical Division and group representation on the Board, the Nominating Committee may seek and solicit the suggestions of individual Divisions or groups.

The Committee may note in this connection that the Chairman of each Division is a voting member ex officio of the Board of Directors during his term in office.

In nominating the Candidate for Director and President, particular consideration should be given to "major interest." It is desirable that the principle of rotation as to primary interest should be a factor in selecting the Presidential candidate.

**Obligations of Directors.** In establishing definite geographical Districts for the selection of Directors, it is the purpose and hope of the Board that an effective liaison between the Board and all sections of the country can be maintained. To this end, each Director will be considered as representing a geographical District. This arrangement, in conjunction with representation of the Divisions, will be effective only to the extent that the Director actually functions in behalf of his District or his Division. It is the duty, therefore, of the Nominating Committee to make it clear to the prospective nominee that, in addition to the honor, the position of Director carries with it definite responsibilities. The Committee should receive from the Local Sections suggesting candidates, or otherwise obtain assurance from the candidate that he is able and willing to undertake these responsibilities.

A Director should plan to attend at least two meetings of the Board, and as many other meetings as is practical, taking into account the distance he resides from New York; he should keep himself informed of the activities of the technical Division and Branch that represents his major interest and should attend meetings of that Division when practical; and he should keep in close touch with the officers of the Local Section or Sections in his district by attending meetings of the Sections or otherwise and should assume a personal responsibility for promoting healthy Local Section activities.

The Board offers this Information and Advice to assist the Nominating Committee in its functions but points out that Article IX, Section 1, paragraph 4 of the Bylaws which reads: "This Committee shall proceed to the selection of candidates and the naming of a ticket. In making such selections the Nominating Committe, shall, so far as practicable, distribute the representation on the Board geographically, provided that seven Directors shall be residents of New York City or the territory within a radius of fifty miles of the headquarters of the Institute" is the mandatory instruction to the Committee and that the interpretation of this paragraph and matters outside its intent are left to the discretion of the Committee.

## NOMINATING COMMITTEE FOR OFFICERS FOR 1951

**Members at Large**

O.B.J. Fraser, Chairman—Assistant Manager, Development and Research Division, International Nickel Co., 67 Wall St., New York, N. Y.

Paul E. Fitzgerald—Dowell Incorporated, 524 Kennedy Bldg., Tulsa 3, Okla.

P. D. I. Honeyman—Inspiration Consolidated Copper Co., Inspiration, Ariz.

**Local Section Representatives**

BOSTON—Raymond B. Ladoo, 42 Huntington Road, Newton, Mass.

(Canada)—H. M. Griffith, Works Mgr., Steel Co. of Canada, Ltd., Hamilton, Ont.

CENTRAL APPALACHIAN—Charles T. Holland, Virginia Polytechnic Institute, Blacksburg, Va.

DELTA—F. E. Simmons, Jr., Houma, La.

DETROIT—Roger F. Mather, Chief Metallurgist, Kaiser-Frazer Corp., Willow Run, Mich.

LEHIGH VALLEY—E. A. Anderson, New Jersey Zinc Co., Palmerton, Pa.

NEW YORK—T. B. Counselman, The Dorr Co., 570 Lexington Ave., New York 22, N. Y.

NEVADA—Louis D. Gordon, Supervisory Engineer, State of Nevada, Mining Section, RFC, Reno, Nev.

OREGON—Pierre R. Hines, 1007 E. Burnside St., Portland 14, Oreg.

SOUTHERN CALIFORNIA—Walter B. Hester, 294 St. Albans Ave., S. Pasadena, Calif.

SOUTHEAST—W. C. Chase, General Superintendent of Mines, Alabama Byproducts Corp., Birmingham, Ala.

SOUTHWESTERN NEW MEXICO—David W. Boise, 917 West St., Silver City, N. Mex.

SOUTHWEST TEXAS—R. C. Granberry, Jr., Humble Oil & Refining Co., Corpus Christi, Texas.

TRI-STATE—George M. Fowler, 608 Joplin National Bank Bldg., Joplin, Mo.

UPPER PENINSULA—Grover J. Holt, Cleveland-Cliffs Iron Co., Ishpeming, Mich.

UTAH—B. E. Grant, U. S. Smelting Refining and Mining Co., 1119 Newhouse Bldg., Salt Lake City, Utah.

## Coming Meetings

*DECEMBER*

**2 Columbia Section, AIME.**
4-7 AIChE, national meeting, Pittsburgh, Pa.
**5 Boston Section, AIME.**
6 Society for Applied Spectroscopy, New York City.
7 American Mining Congress, Annual Business Meeting, New York City.
**7 Chicago Section, AIME. W. C. Schroeder on synthetic liquid fuels.**
**7 New York Section, AIME. L. E. Young on research in coal mining.**
**8-10 Seventh Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.**
**9 Rio de Janeiro Section, AIME.**
**9 St. Louis Section, AIME, York Hotel.**
**13 Delta Section, AIME. W. H. Skinner on gas condensate well corrosion problems.**
**13 East Texas Section, AIME.**
**14 Connecticut Section, AIME. F. H. Wilson on intergranular parting of 70:30 brass.**
**14 El Paso Metals Section, AIME.**
**14 San Francisco Section, AIME.**
**15 Carlsbad Potash Section, AIME.**
**15 Utah Section, AIME.**
**16 Oregon Section, AIME.**
**19 Detroit Section, AIME.**
**20 Gulf Coast Section, AIME.**
**20 Washington, D. C., Section, AIME.**
**21 Southwest Texas Section, AIME.**
**26 Alaska Section, AIME.**
26-31 AAAS, Penn zone hotels and Columbia Univ., New York City.
**27 Montana Section, AIME.**

*JANUARY 1950*

**2 Boston Section, AIME.**
**4 Chicago Section, AIME. T. B. Counselman on Fluidization of Solids in Noncatalytic Operations.**
**6 Columbia Section, AIME.**
**10 Delta Section, AIME. Water injection.**
**10 East Texas Section, AIME.**
**11 El Paso Metals Section, AIME.**
**11 San Francisco Section, AIME.**
**11 Southwestern New Mexico Section, AIME.**
**13 Rio de Janeiro Section, AIME.**
**16 Minnesota Section, AIME. Annual meeting, Hotel Duluth, Duluth, Minn., Mining symposium conducted by the Center of Continuation Study, of the Univ. of Minn. follows annual meeting on Jan. 17 & 18.**
16-19 Plant Maintenance Show, 4-day exposition and conference, Auditorium, Cleveland, Ohio.
18-20 American Society of Civil Engineers, annual meeting, New York.
30-Feb. 3 AIEE, winter meeting, Hotel Statler, New York.

*FEBRUARY 1950*

**10 Southwestern Section, Open Hearth Steel Committee, Iron and Steel Division, St. Louis, Mo.**
**12-16 Annual Meeting, AIME, Statler Hotel, New York City.**

*APRIL 1950*

4-7 Nat'l Assn. of Corrosion Engineers, St. Louis.
**10-12 Open Hearth Conference, and Blast Furnace, Coke Oven and Raw Materials Conference, Netherland Plaza Hotel, Cincinnati.**
19-21 American Society of Civil Engineers, spring meeting, Los Angeles.
23-26 American Ceramic Society, annual meeting, New York City.
24-26 AMC Coal Convention, Netherland Plaza Hotel, Cincinnati, Ohio.
25-26 Annual Metal Powder Show, Book-Cadillac Hotel, Detroit.

*OCTOBER*

21-27 National Metal Congress, Chicago.

*DECEMBER 1950*

**7-9 Electric Furnace Steel Conference, Iron and Steel Div., Hotel William Penn, Pittsburgh.**

*APRIL 1951*

**2-4 Open Hearth and Blast Furnace, Coke Ovens and Raw Materials Conference, Iron and Steel Division, Statler Hotel, Cleveland.**

## Conditions Under Which 1950 Publications Are Available to Members

Pursuant to Article X of the By-laws of the AIME, the following information is hereby given as to the "conditions, prices, and terms under which the various classes of members, and Student Associates, severally, shall be privileged to obtain publications of the Institute during the ensuing year."

Publications authorized for 1950 publication include the following:

**Mining Engineering,** published monthly, containing material, including technical papers, of interest to those engaged in exploration, mining geology and geophysics, and metal, nonmetallic, and coal mining and beneficiation, and fuel technology.

The **Journal of Metals,** published monthly, containing material, including technical papers, of interest to those engaged in nonferrous smelting and refining, iron and steel, and physical metallurgy.

The **Journal of Petroleum Technology,** published monthly in Dallas, containing material, including technical papers, of interest to those engaged in petroleum production.

Current copies of any one of the above journals will be supplied to all members in good standing without further charge. (A member ceases to be in good standing if current dues are not paid by April 1.) If more than one of the monthly journals is requested, $4 extra will be charged for an annual subscription, or 75 cents for single copies. The nonmember subscription price for each journal is $8 in the Americas; foreign, $9. Student Associates who pay dues of $4.50 will be entitled to the same privileges for all publications as members except as noted below; those who pay $2 will not receive individual subscriptions to the journals but otherwise have the same privileges.

Three volumes of "Transactions" are authorized for 1950 publication, as follows: No. 184, Mining Branch; No. 185, Metals Branch; and No. 186, Petroleum Branch. These volumes will be available to paid-up members at $3.50 each for a first copy. Nonmembers $7 in the United States; foreign $7.50.

Special volumes now planned for publication in 1950 include the following:

(1) Open Hearth Proceedings. Price to AIME members, $7.50; to students in accredited colleges in the United States, $3.

(2) Blast Furnace, Coke Oven, and Raw Materials Proceedings. AIME members $5; students as above, $2.50.

(3) Electric Furnace Steel Proceedings. AIME members $7; students as above, $3.

(4) Symposium on Tube Production Practice. Price to be set.

(5) Basic Open Hearth Steelmaking, 2d ed. Price to be set.

(6) Statistics of Oil and Gas Development and Production. AIME members $3; nonmembers $6.

(8) Conservation of Petroleum, by Stuart Buckley. Date of publication and price to be determined.

(9) Coal Preparation, 2d ed. Price to members $4 for one copy; additional copies at nonmember price of $8.

If dues are paid subsequent to Jan. 31, back issues of Institute publications will be supplied only if adequate stocks are on hand. A member may not receive a volume of "Transactions" or a special volume in lieu of a monthly journal, free of charge on membership. Members in arrears for dues are not entitled to special members' prices for publications.

Rocky Mountain Members may have their choice of an annual subscription to one of the monthly journals on request.

## What Went on at Recent Local Section Meetings

| SECTION | DATE | ATTENDANCE | SPEAKER, AFFILIATION, AND SUBJECT |
|---|---|---|---|
| Alaska | Oct. 24 | 22 | H. G. Wilcox, RFC, on history and purpose of the RFC. |
| Black Hills | Sept. 16 | 51 | N. Herz, Homstake Mining Co., on postwar metallurgical problems. |
| Boston | Oct. 3 | 68 | R. L. Nichols, Tufts College, on the Arctic and Antarctic. |
| Carlsbad Potash | Sept. 15 | 85 | L. E. Young, President, AIME, on mining aspects of the ECA. |
| Carlsbad Potash | Oct. 20 | 50 | A. G. Wolf, Texas Gulf Sulphur Co., on sulphur from sulphur domes. |
| Chicago | Sept. 14 | 85 | Sir Charles Goodeve, British Iron and Steel Research Assn., on organization and work of the Association. |
| Colorado | Oct. 11 | 86 | L. E. Young, President, AIME. |
| Columbia | Oct. 7 | 13 | J. P. Spielman, Washington State College, on curriculum for mining schools. |
| Connecticut | Oct. 12 | 32 | A. Phillips, Yale Univ., on metallurgy in Brazil. |
| El Paso Metals | Sept. 13 | 82 | L. E. Young, President, AIME, on technical assistance to foreign countries. A. C. Serrano, Mexican official, on mining industry of Mexico. |
| Gulf Coast | Sept. 20 | 115 | A. W. Bounds, Stanolind Oil & Gas Co., on legal and political history of the Tidelands controversy. |
| Kansas | Sept. 7 | 62 | J. E. Smith, Johnson Oil Field Service Co., on drill stem testing in open hole. |
| Lehigh Valley | Sept. 7–8 | 43 | Annual inspection trip, N. J. Zinc Co. mine and mill. |
| Lehigh Valley | Oct. 21 | 84 | J. E. M. Wilson, Jeffrey Mfg Co., on mechanical mining of bituminous coal. |
| Montana | Oct 13 | 110 | L. E. Young, President, AIME. |
| North Pacific | Sept. 22 | 51 | E. A. Cocanower and L. Heinzinger, Bethlehem Pacific Steel Corp., on the history of Western steel industry, and purchasing raw materials for a Seattle plant, respectively. |
| North Pacific | Oct. 17 | 60 | L. E. Young, President, AIME. |
| New York | Sept. 7 | 112 | E. Just, ECA, on current strategic materials development in the ERP. |
| New York | Oct. 13 | 103 | M. L. Haider, Imperia Oil, Ltd., on Canadian oil developments. |
| Ohio Valley | Sept. 27 | ..... | G. von Stroh, BCR, on an analysis for a continuous mining machine. |
| Ohio Valley | Oct. 13 | 35 | B. D. Blackie and B. W. Dunnington, students, Ohio State Univ., on looking Labrador over, and corrosion at elevated temperatures, respectively. |
| Pennsylvania-Anthracite | Oct. 28 | 180 | J. R. Hoffert, dept. of health, Commonwealth of Pa., on abating stream pollution. |
| Rio de Janiero | Sept. 8 | ..... | A. I. de Oliveira, National Petroleum Council, on petroleum and refineries in Bahia. |
| Rio de Janiero | Sept. 22 | ..... | L. J. de Morais, Cia. Acos Especiais de Itabira on company activities and objectives. |
| Rio de Janiero | Oct. 13 | ..... | S. F. Abreu, Brazilian delegate to UNSCCUR, on meeting and visit to oil shale plant. |
| Southwest Texas | Sept. 14 | 233 | J. L. P. Campbell, Lane Wells Co., on the correlation of gamma ray and neutron radioactive well logs. |
| Southeast | Oct. 4–5 | 96 | L. E. Young, President, AIME. |
| Southeast | Oct. 21 | 119 | A. C. Fieldner, USBM, on coal and its utilization. |

# Personals

**Robert E. Baarson** is working for the Eagle-Picher Co. as an engineer in exploratory research. His address is 2512 Main St., Joplin, Mo.

**T. H. Barrett,** formerly associate professor at Robert College, Istanbul, Turkey, is teaching at Michigan College of Mining and Technology, Houghton. He was recently reelected a director of the Construction Men's Association of New York City, but expects to have time for some consulting work.

**Oliver W. Borgeson,** a '49 graduate of Michigan College of Mining and Technology, is sales representative in the Lake Superior district for the Mine Safety Appliances Co. His address is 617 N. 10th Ave. E., Duluth 5.

**Everett O. Bracken** received his B.S. degree in geological engineering from the Montana School of Mines in June and is employed by the Silver King Coalition Mines Co. at Park City, Utah, as a junior geologist.

**Andre L. Brichant** has taken up his duties as manager of the Belgian Government trade exhibition in Kansas City, Mo. The exhibition opened at the end of October and will be of a permanent character.

**Joseph F. Brown** worked last summer for the Lehigh Navigation Coal Co. and then returned to Columbia to study for an EM degree under a Krumb Fellowship.

**Charles H. Burgess,** mining consultant and geologist, succeeded **Evan Just** as director of the strategic materials division of ECA on Nov. 14. After more than sixteen months as director, Mr. Just returned to the editorship of E&MJ. Mr. Burgess had been deputy director of the ECA division since October 1948. He had worked for Anaconda and the Quartz Hill Mining Co. and during the war was with the BEW, OPA, and WPB.

**Donald Carlisle** is a lecturer in the department of geology at the University of California at Los Angeles.

**D. J. Christie** has left S. W. Africa, where he was a metallurgical engineer for the Tsumeb Corp., to become a student at the Harvard Business School.

**A. F. Crosby** recently took the post of mill superintendent with the New York and Honduras Rosario Mining Co., San Juancito, Honduras.

**James W. Crosby, III,** recently took the post of junior mining geologist with the California State Division of Mines and Geology. His address is 543 Ramsell St., San Francisco 27.

Herbert Hoover

**Herbert Hoover** received the Frederick W. Taylor Key of the Society for Advancement of Management on Nov. 3, in recognition for his services to the nation as chairman of the Commission on Organization of the Executive Branch of the Government. The key is presented annually for the outstanding contribution to the advancement of the art and science of management as conceived by F. W. Taylor, pioneer of scientific management.

On Feb. 10 Mr. Hoover will be one of the recipients of the 10th annual Moles award. The Moles, composed of men now or formerly engaged in the construction of tunnel, subway, sewer, foundation, marine, subaqueous, or other heavy construction, honor one member and one nonmember for their contributions to the construction field and for their achievements as citizens. Mr. Hoover is the 1950 nonmember recipient.

**Erle V. Daveler,** vice-president and director of the American Zinc, Lead and Smelting Co., married Mrs. Lola Bullard at the Church of St. Ignatius Loyola, New York City, on Oct. 27. Mr. Daveler, a director of the AIME, is chairman of the Institute's Finance Committee.

**C. B. E. Douglas,** after spending most of the summer in Alaska, returned to the Boston office of the U. S. Smelting Refining and Mining Co., which is now his headquarters.

**Johannes S. Enslin** is inspector of mines, Department of Mines in Johannesburg, S. Africa.

**A. W. Estey** can now be addressed in care of Nicholson Mines Ltd., Box 42, Fort McMurray, Alta.

**K. R. Fleischman** is mining engineer and metallurgist for Dickson Primer & Co., Pty., 73 Day St., Sydney, N.S.W., representing Metal Traders Ltd., London, and Metal Traders Inc., New York, in their metal and ore buying interests throughout Australasia.

**J. F. Frost** left the Northern Peru Mining and Smelting Co. in Trujillo to go to Buchans, Newfoundland, where he can be reached in care of the Buchans Mining Co.

**E. D. Gardner** took up permanent duties at Washington, D. C., on Oct. 20 as chief mining engineer with the Bureau of Mines. He had been in Denver, working on oil shale.

Walter R. Brown

**Walter R. Brown** has bought a home at 3320 NW 4th St., Miami 35, Fla., in which to house his family while he is away. At the moment he is not engaged in mining work but has hopes of some for the future.

**I. G. Irving,** mining engineer of Butte, and his associates are carrying on active development work at three properties in Montana which were prominent a number of years ago, the Pyrenees, the Spar, and the Norwich mines.

**Dean D. Kerr** graduated from the University of Kansas in August and is employed by the Utah copper division of the Kennecott Copper Corp.

His address is 55 2nd Ave., Midvale, Utah.

**Edward J. Lee** can be reached at 746 Madison Ave., Scranton, Pa. He is an engineer with the Hudson Coal Co.

**Hsin Te Lee** is working for the Grandview Mine at Metaline Falls, Wash., as assayer.

**Paul Linz** has been made chairman of the board of directors of the South American Minerals and Merchandise Corp. He continues as personal assistant to **Mauricio Hochschild** in all his enterprises. SAMINCORP represents Hochschild interests in Peru, Bolivia, Chile, Argentina, and Brazil.

**Orville R. Lyons** left Battelle Memorial Institute on Nov. 1 to become coal preparation engineer with Heyl & Patterson, Inc., Pittsburgh.

**Vernon L. Mattson,** former chief engineer for the Consolidated Feldspar Corp., is director of the Colorado School of Mines Research Foundation. His home address is 1198 Pikeview St., Lakewood Station, Denver.

**G. C. McCartney** recently moved his consulting office to 15 King St. W., Toronto 1, Ont. He is devoting considerable time to the search for uranium deposits, especially in the Lake Athabaska area of Northern Saskatchewan.

**L. Charles McHenry,** who graduated from Missouri School of Mines last June, is an engineer with the Tennessee Coal, Iron and Railroad Co. His address is 2208 Clarendon Ave., Bessemer, Ala.

**Edward C. Meagher,** treasurer of the Texas Gulf Sulphur Co., has been re-elected president of United Engineering Trustees. **James L. Head,** Chile Exploration Co., was re-elected assistant treasurer and **John H. R. Arms** continues as secretary.

**William L. Merritt** has opened a consulting mining engineering office at 1108 Hobart Bldg., 582 Market St., San Francisco 4, and has discontinued both the Ohio and Sanger, Calif., addresses.

**Melbourne W. Miller** graduated from the Colorado School of Mines last May and is employed by the Euclid Road Machinery Co. of Cleveland, Ohio, as a field engineer.

**R. C. Morgan** is working as a junior engineer for the Columbia Iron Mining Co. at the Iron Mountain mine. His address is 171 S. 100 E., Cedar City, Utah.

**Frank Noe,** of the Bureau of Mines, has been transferred from the Salt Lake City office to Rio de Janeiro where he has been assigned to work with the Departmento Nacional da Producao Mineral of the Brazilian government.

Just thirty years ago, when Horace Winchell was President of the AIME and Herbert Hoover had been selected as the President for the ensuing year, **Grace Pugsley,** then barely out of kindergarten, applied for a job at Institute headquarters and got it. In addition to the stenographic competence which is possessed by most young ladies entering business life, she brought to her new job, as it proved, a natural interest and ability in both the editorial and advertising phases of the publishing business; a cheerfulness that enabled her to get along with even the most difficult advertising managers (editors are usually not troublesome); and an in-

born desire and energy to do the job before her as well as possible, with no complaint about occasional overtime or the extra assignments that fall to the lot of a willing worker.

In the years since 1919 most of Grace Pugsley's work has been in one capacity or another on the magazines that the Institute publishes, and in recent years she has been secretary and assistant to the advertising manager of Mining and Metallurgy and Mining Engineering and production manager of these journals and of the annual Directory. Having served longer than any one else on the AIME staff, she has often been its spokesman and representative, and naturally is one of the chief figures in such social events as the Christmas staff party. Five years ago she became Mrs. E. F. Stickle. Two other young ladies who joined the Institute staff within a year after Grace Pugsley—Grace Townsend and Irene Klein—are also still on the roll.

The Secretary, who joined the Institute as a Member the same time that Grace did as an employe unites with the staff in congratulating her on thirty years of faithful and highly competent service. She is the kind of person with whom we have all enjoyed working.

Sidney J. McCarroll

**Sidney J. McCarroll** resigned as manager of Minerales de Nacozari on Nov. 1. This resignation coincides with the withdrawal of American interests from the company, which is now Mexican controlled. His present address is 1446 12th St., Douglas, Ariz.

**Thomas B. Rees** has taken over the Charleston-Logan, W. Va., territory for the Goodman Mfg. Co. as sales engineer. He had been in the Pittsburgh and Huntington territories. On Oct. 3 he moved his family from Signal Mt., Tenn., to 9 Estill Drive, Charleston, high above the Kanawha River. Mr. Rees has also been associated with the Ross Meehan Foundries, Hedges Mfg. Co., Johns Manville, and Combustion Engineering.

**Stuart St. Clair** returned to New York in October after "20,000 miles over Africa" by air safari. He represented Overseas Consultants, Inc., of New York City, who, in conjunction with the engineering firm of Sir Alexander Gibb & Partners of London, conducted a reconnaissance survey of a proposed connecting link between the Rhodesian and East African Railway Systems for the British Colonial Office. The trip took three months and included all of Tanganyika and much of Kenya, Nyasaland, and N. and S. Rhodesia, and a little of Belgian Congo and Portuguese East Africa.

**Robert T. Sanden,** recent graduate of the University of Minnesota, is an assistant research engineer for the M. A. Hanna Coal and Ore Co. He can be reached at 2623½ 1st Ave., Hibbing, Minn.

**Donald J. Saunders** is attending the University of Minnesota graduate school, working for an M.S. degree in geology.

**Carl W. Sawyer** is a metallurgist at King Lease Inc., Ouray, Colo. The mine, located about six miles from Ouray, produces lead, zinc, gold, and silver.

**Alan A. Sharp,** stationed with the Bureau of Mines health and safety division at Phoenix, was recently transferred to Denver, which has just been designated as regional headquarters for the Bureau's Rocky Mountain area. Having cut his eye teeth in mining around Colorado, he finds the change welcome and anticipates good skiing within short driving distance from the mile-high city.

**Philip J. Shenon** is now in Salt Like City filling the post of chairman of the division of mineral engineering at the School of Mines of the University of Utah.

**Robert H. Shepard** has accepted the post of compány geologist with Malco Refineries, Inc., of Roswell, N. M. He had been with the U. S. Geological Survey.

**Daniel C. Shewmon** has become an instructor with the mining department of West Virginia Institute of Technology, Montgomery, W. Va., after working nearly five years with the New Jersey Zinc Co., both in New Jersey and Virginia.

**John P. Skinner** has been transferred from Franklin, N. J., by the New Jersey Zinc Co. to the Eagle mine in Gilman, Colo., as assistant mine foreman.

**Alex J. Speal** has been employed as assistant mine engineer by the Richard Ore (Iron) Co., Wharton, N. J., since graduating from Lafayette College as a mining geologist in June. His address is Box 243, Mt. Hope Rd., Rockaway Township, N. J.

**Hugh S. Spence** has retired from the Mineral Resources Division, Canadian Bureau of Mines, after 39 years of service. The Bureau's specialist in a wide range of industrial minerals, he is also an authority on radioactive minerals having made the first official report on the pitchblende discoveries at Great Bear Lake in 1931. His Prospector's Guide to Uranium and Thorium Minerals has had the widest circulation of any publication put out by the Bureau. Now he intends to engage in private consulting practice, with an address at 222 Argyle Ave., Ottawa, Ont.

**Harvey W. Smith** graduated from the Colorado School of Mines last May and is now employed by the Magma Copper Co., Superior, Ariz. Mail reaches him at P. O. Box 587, Superior.

**Ernest M. Spokes,** after acquiring a M.S. degree in mining engineering in August, was made assistant professor of mining engineering at the University of Kentucky on Sept. 1.

**Edward Steidle, Jr.,** is in Paris as an engineer adviser on mine mechanization for the Joy Mfg. Co.

**W. R. Storms** has been transferred by the Bureau of Mines from Silver City, N. Mex., to Tucson, Ariz., where his address is 4020 E. Whitman St.

Rinaldo V. Taborelli

**Rinaldo V. Taborelli** went to the New Mexico School of Mines in October as development contract officer at the school, whose research and development division has a contract with the Bureau of Ordnance. Along with his regular duty, the present assignment affords interesting contact with his neglected profession—mining.

**G. Douglas Strachan** has been with the United States, Philippine War Damage Commission in Manila since July, 1948. At the present time he is in charge of the mining section, with the full responsibility of appraising and adjudicating all mine damage claims.

**Weston Thomas,** formerly with the Potash Co. of America, is now with the Climax Molybdenum Co., New York City. His new residence address is 191 Main St., Southport, Conn.

**George A. Thompson, Jr.,** has been made assistant professor of the Stanford School of Mineral Sciences.

**Verle B. Utzinger,** former student at the University of Illinois, is now field engineer for the Muller Co., Decatur, Ill.

**John Vanderwilt** spent last summer in Norway as a consultant for the Strategic Materials Division of the ERC. He traveled extensively in Norway, examining the iron deposits of Sydvaranger near Kirkenes and the Dunderland deposits, north east of Mo i Rana. The concentrating plant at Kirkenes was completely destroyed in 1944 by the retreating Germans and much of the destruction is still evident although a large part of the town has been rebuilt. Reconstruction of the plant is underway, aided by ECA funds, with partial completion hoped for in 1951. A steel plant is under construction at Mo i Rana. Pyrite ores are probably the most important; Mr. Vanderwilt saw representative deposits. Of the mica, nickel, copper, cobalt, manganese, graphite, and a few nonmetallic minerals, graphite is the most important at the moment. Norway has not had, and still is not having, an easy time, but they are working hard and no doubt will rebuild the forty percent of their industrial wealth destroyed by the war.

**Thomas R. Van Fleet,** who graduated from the University of Arizona last May, is working for the U. S. Vanadium Corp., in Uravan, Colo., as a mining engineer.

**Howard L. Waldron** is working on a training program with the Buaas Drilling Co. His new address is 2331 Parkway, Bakersfield, Calif.

**Stanton Walker,** director of engineering of the National Sand and Gravel Association, Washington, D. C., announces the removal of the Association's laboratory to its new location, Building H of the Martin Engineering College, Washington. Extensive new equipment and facilities are being provided.

**Robert R. Wallace** has completed his studies at the Michigan College of Mining and Technology and is working as a mining engineer with the Oliver Iron Mining Co. in Hibbing, Minn.

**Paul Weir,** president of the Paul Weir Co., mining engineers and geologists, Chicago, recently spent several weeks inspecting coal mining developments for the Turkish government. He supervised five American mining engineers, geologists, and management consultants who reviewed plans and specifications for modernization of key mines in the Turkish Zonguldak field with American equipment and methods. Before returning to this country, Mr. Weir toured mines in Great Britain to check progress of test installations of American equipment and methods in British mines.

**Reed F. Welch** succeeded **Brent N. Rickard** as manager of the Tucson ore-buying office of the American Smelting and Refining Co. on Oct. 1. Mr. Rickard, because of recent illness, is retiring from active duty but will remain in an advisory capacity until July 1, 1950. Mr. Welch has had ex-

tensive experience in the purchase of ores and concentrates, having acted as ore buyer in the Company's Salt Lake City office since 1937.

Howard J. Vander Veer

**Howard J. Vander Veer** has been appointed chief of the division of adjudication in the Colorado-Utah region of the Bureau of Land Management. He is responsible for all BLM mineral activities in the area, and supervises all homestead, rights-of-way, recreation, and other uses of the public lands administered by the BLM. He is the first mining engineer who has ever been appointed head of a regional division in BLM

**Sam West** is doing graduate work in geology and mineralogy at the University of Arizona, Tucson.

**Jerry F. Whalen,** upon graduation from the Colorado School of Mines last July, took the job of mining engineer in the coal division of Eastern Gas and Fuel Associates and is located at Helen, W. Va.

**Glen B. Wilson** has the job of mine superintendent with the Crown Point Mining Co. His address is Box 761, Globe, Ariz.

**Harry J. Wolf,** mining and consulting engineer, has established his office at 420 Madison Ave., New York City.

**Rudolph G. Wuerker** has the post of assistant professor in mining at the University of Illinois, Urbana.

**Charles Will Wright** sailed for Europe in October. He will visit Athens, Rome, Paris, Madrid, Lisbon, and London, and can be addressed in care of the American Embassies in these cities. Besides getting information on certain mine development projects, he will make a study of the present mining legislation, exchange controls, labor conditions, taxes and tariffs, and the changes that are being considered to encourage better co-operation between local and foreign mining interests for increased output of strategic minerals under private enterprise.

## —In the Metals Branch—

**Robert W. Bohl** has been made assistant professor in the department of mining and metallurgical engineering at the University of Illinois.

**Gerard H. Boss** left the aeronautical materials lab., metallurgical division, of the Philadelphia Naval Base last May to join the metallurgy division of the Oak Ridge National Lab., Oak Ridge, Tenn.

**W. L. Brown** lives at 928 7th Ave. N.W., Great Falls, Mont. He is president and general manager of the General Distributing Co. in the oxy-acetylene and electric welding supply business with distribution throughout central Montana.

H. J. Kozlowski

**H. J. Kozlowski,** for the past 4½ years a research metallurgist in the physical metallurgy division of the Bureau of Mines at Ottawa, is on leave of absence to take graduate studies in physical metallurgy at Yale.

**C. L. Clayton** became affiliated with Geo. D. Clayton and Sons, Insurance, of Hannibal, Mo., on Nov. 1.

**Warren P. Chernock,** formerly a student at Columbia School of Mines, is now in the X-ray section of the metallurgy division of the Argonne National Lab. He lives at 311 S. West Ave., Elmhurst, Ill.

**A. A. Conrad, Jr.,** has been transferred by the Lorain Works of the National Tube Co. to the U. S. Steel Corp. of Delaware research laboratory for a period of training in research work. He is addressed at the lab., Lincoln Highway, Kearny, N. J.

**George S. de Moraes** graduated from Carnegie Tech last June and is now working as a metallurgical engineer at the Air Depot of the Brazilian Air Force in Sao Paulo.

**Paul Dixon, Jr.,** after completing work for his M.S. degree in metallurgy at Columbia, joined the metallurgical research department of the Chrysler Corp. in Detroit.

**W. E. Duckworth** has become research investigator with the Glacier Metal Co., Alkerton, Wembley, England.

**Sanford A. Estes** is chief metallurgist for the Hoyne Iron and Steel Co. He can be reached at 4901 Drexel Blvd., Chicago.

**Henry E. Frankel** recently took the job of research assistant at the metals research lab. of the Carnegie Institute of Technology. His present address is 4016 Saline St., Pittsburgh 17.

**Arthur E. Franks** is project manager of the metals research department of the National Research Corp., 70 Memorial Drive, Cambridge 42, Mass.

**Thomas E. Groce** is employed by the Kaiser Aluminum Co. at Newark, Ohio.

**G. B. Hamilton, Jr.,** a recent graduate from the Case Institute of Technology, is with the General Electric Co. in Schenectady, N. Y. He is a foundry engineer in the steel foundry of the Schenectady works.

**Gene W. Hinds** is a metallurgical engineer with the Geneva Steel Mill in Provo, Utah.

**Joseph H. Hoage** married Margaret Gordon in Denver on Oct. 23. They will make their home at 1314 Stevens Drive, Richland, Wash. He is with G. E. in Richmond.

**John J. Howard,** who retired from E. J. Lavino & Co. last year, can be reached at Garden Court, 47th and Pine Sts., Philadelphia 43.

**George J. Jameson** has transferred from the Technical Group, Naval Supply Depot, Clearfield, Ogden, Utah, to the Inspection Division, Seattle Supply Center, Bureau of Federal Supply. His primary duty is strategic and critical materials inspection.

**Percy E. Landolt,** consulting engineer of New York City, has been relected president of the Asscciation of Consulting Chemists and Chemical Engineers.

**Robert E. Lenhart** is working for the General Electric Co. His address is 6 Union St., Schenectady, N. Y.

**R. J. Loree** is associated with Sherritt Gordon Mines Ltd. at their pilot plant in Ottawa, Ont.

**Robert N. Lynch** became sales manager of the heat treating materials division of the Park Chemical Co., Detroit, on Oct. 1. With the company for ten years, he had been working as metallurgical sales and service engineer in the Michigan-Ohio territory.

**M. Meriub-Sobel** has been appointed associate professor of chemical engineering and metallurgy at the Hebrew Institute of Technology, Haifa, Israel.

**Jordan S. Murray** is a junior process engineer with the U. S. Potash Co. His address is 407 S. Lake St., Carlsbad, N. Mex.

Bernard S. Lement

**Bernard S. Lement,** formerly on the research staff at MIT assigned to a project on the dimensional stability of metals, received his Sc.D. degree in metallurgy there, and is now assistant professor of metallurgy at the University of Notre Dame.

**V. A. Phillips** has returned to England after completing graduate studies at the Hammond Metallurgical Lab., Yale, and is a research student at the Cavendish Lab., Cambridge, England.

**Maurice Sadowsky, Jr.,** is in the employment of the Inland Steel Co. at Gary, Ind., as a metallurgical trainee.

**James Howell Smith,** formerly in the research department of the Metals Refining Co., division of the Glidden Co., Hammond, Ind.. has transferred to New York City as sales representative of Metals Refining in the Eastern states. His headquarters are at Rm. 802, 52 Vanderbilt Ave. Recently Mr. Smith was commissioned a Captain in the Chemical Corps of the U. S. Army Reserve.

John P. Spielman

**John P. Spielman,** formerly professor of metallurgy at the Montana School of Mines, has been appointed dean of the School of Mines at the State College of Washington. His address is 1619 Fisk St., Pullman, Wash.

**H. T. Sumsion,** previously with the University of Utah, is now senior research engineer in the research department of the Carborundum Co., Niagara Falls, N. Y.

**Samir Tahir** has become metallurgist in the chemical department of the Egyptian Government. His address is 22 Dar El Shefa St., Garden City, Cairo.

**Lars H. Villner** is a research engineer for Jernkontoret in Stockholm.

**Theo J. Voll** recently became metallurgist for the Keystone Carbon Co. His address is Box 146A, Rt. 1, Saint Marys, Pa.

## —In Petroleum Circles—

**Philip N. Bailey,** formerly with the Union Oil Co. of California, is taking graduate work at the University of Tulsa.

**Douglas Ball** went on leave of absence from the Phillips Petroleum Co. in July to become assistant to Max Ball, oil and gas consultant, in Washington. He is also attending classes at George Washington University. Mr. Ball recommends observance of certain portions of the fauna of downtown Washington at lunchtime for all engineers and geologists, especially on breezy days.

**John R. Brack** is employed by the Ohio Oil Co. as a trainee at the Yates field in Iraan, Texas. He gets his mail at Box 523, Iraan.

**Joe Chastain** is engineer representative for the Bethlehem Supply Co., Midland, Texas.

**Lester D. Collier** is a junior geologist with the Union Oil Co. of California at Shreveport, La.

**J. E. Eckel** resigned from the Oil Center Tool Co. on Oct. 15. His address is 300 Carson Court, Houston 4.

**Joy Elledge** is progress engineer for the Transcontinental Gas Pipe Line Corp. Mail goes to his home at 1002 Annex, Dallas.

**Earl Ellis** has a job as geophysicist with the Humble Oil and Refining Co. His mail goes to Box 212, Franklin, La.

**F. A. Graser** has returned to the ranks of petroleum consultants with his office at his home 421 Oak Lane, San Gabriel, Calif., after a year with the Cleveland Oil Co. in Los Angeles.

Harvey T. Kennedy

**Harvey T. Kennedy** has joined the staff of the petroleum engineering department of Texas A&M as distinguished professor of petroleum engineering. He had been with the Gulf Research and Development Co. in Pittsburgh.

**Lloyd A. Hamann** graduated from the University of Southern California last June. He is employed by the Stanolind Oil and Gas Co., working as an engineer trainee in the Slaughter area near Brownfield, Texas.

**R. D. Horst** is working as an engineer trainee with the exploitation department of the Shell Oil Co. At present his assignment is at the Weeks Island field, La.

**Harry L. Horton** has become associated with Dowell Incorporated as a junior engineer.

**John B. Hundley, Jr.,** went to work with the Richfield Oil Corp. last April. He is working in the production department at Cuyama Valley, Calif.

V. Dale Martin

**V. Dale Martin** resigned as head of the land department for the Venezuelan Atlantic Refining Co. in Caracas, to return to the States, where he is engaged in the promotion of certain oil properties for his own account. His address is 326 N. Minnesota Ave., Columbus, Kans.

**E. C. Jacobsen** is a geologist for the Standard Oil Co. of California. He is working in the Los Angeles Basin and living at 632 Longfellow, Hermosa Beach, Calif.

**A. A. McArthur** is a reservoir engineer trainee with The Texas Co. His mail goes to Box 827, El Campo, Texas.

**Paul Meadows** graduated from Texas Tech last January and is working for the Bureau of Mines petroleum experiment station at Bartlesville, Okla., as a petroleum engineer.

**Edward B. Kuhne** is an engineer revenue agent with the Bureau of Internal Revenue, stationed in New Orleans. He was with the Halliburton Oil Well Cementing Co.

**Joe A. Laird** is a member of the faculty of the department of petroleum engineering at Texas A&M College, College Station.

**Howard C. Lawton** has recently entered the consulting business and has set up the Lawton Research Laboratory at Fillmore, Calif. He will study problems on rotary drilling fluids, well reconditioning methods and analyses.

**William A. Libby** works as a guide for the National Park Service at Carlsbad Caverns in New Mexico. He graduated from Texas College of Mines last May.

**Theodore A. Link,** consulting geologist of Toronto and Calgary, and vice-president of the AAPG and GAC, has been giving a series of lectures sponsored by the AAPG. He has visited Vancouver, Los Angeles as well as parts of West Texas and New Mexico.

**Carl Lund** has the post of sales and advertising manager with the Loeffler-Greene Supply Co. in Oklahoma City, Okla.

**Edgar N. Mills** has the job of junior engineer with the Pan American Production Co. His mail is sent to Box 241, Silsbee, Texas.

**T. Noordhuis** is in The Hague, Netherlands, as production engineer for Bataafsche Petroleum Maatschappy.

**Joseph E. Pogue,** head of the Chase National Bank's petroleum department, will relinquish his position as a Chase vice-president at the end of the year, but will retain his close affiliation with the bank in a consulting and advisory capacity on a part-time basis. He will continue his present office at 18 Pine St., New York City.

V. J. (Mike) Mercier

**V. J. (Mike) Mercier** has been made sales manager for the Mountain Iron and Supply Co., Wichita, Kans. Formerly with the Lane-Wells Co., he is well known in the Mid-Continent for his many papers on well logging and geophysics.

**Marvin A. Remke** was transferred in August to the Phillips Petroleum Company's West Texas district as staff engineer on operational problems. Now strictly in oil territory, he lives at 302 N. Kelley, Odessa, Texas.

**Clovis E. Rodelander** is roustabout engineer for the Stanolind Oil and Gas Co., Box F., Hobbs, N. Mex.

**Robert L. Richardson** graduated from USC in June of 1948 and that August went to work for the Rocky Mountain Drilling. After five months on the rig floor he went into the main office as a junior engineer. This April he and Betty McCall were married.

Robert G. Hill

**Robert G. Hill** recently resigned as assistant to the district superintendent of the Texas Petroleum Co. in Venezuela, to do graduate work in the department of mineral economics at Penn State.

**F. L. Schenck** has left the Atlantic Refining Co. to go with Oil Properties Consultants of Pasadena, Calif., as a geologist.

**Albert G. Sledge, Jr.,** joined the production department of the Skelly Oil Co. at Velma, Okla., last June as a petroleum engineer and in October was transferred to Carthage, Texas.

**Gordon T. Swanby** is a geophysicist with the Stanolind Oil and Gas Co. at Craig, Colo.

**Scott L. Taliaferro** has left the Stanolind Oil and Gas Co. His present work is that of consulting engineer in the partnership of Taliaferro and Slicker, 203 Judia Bldg., Cisco, Texas.

**L. K. Van Dongen** is a consulting engineer with Arthur G. McKee & Co. He receives mail at 115 W. 69th St., New York City 23.

**William R. Waag** is a training petroleum engineer with the Sohio Petroleum Co., working on production and drilling in the Illinois district.

**H. Edward Wendt** graduated from Texas A&M in June with degrees in both petroleum and mechanical engineering. That same month he went to work for the Tidewater Associated Oil Co. in the Hobbs, N. Mex., district.

# Obituaries

### Army Adams

AN APPRECIATION BY JACK M. EHRHORN

Army Adams died of wounds of a gun accident on the rifle range at Grass Valley, Calif., on Aug. 20, 1949. He had been practicing his marksmanship in anticipation of the coming deer season.

Army was born in Montrose, Colo., on July 27, 1884. His father, John Adams, was a West Point Cadet who served as a member of the West Point Military Academy Escort which accompanied President Lincoln to the White House. The unusual name of Army had this origin. Army attended Montana University School of Mines where he studied mining engineering. Army Adams married Miss Alice Gregory in Colorado in 1910. His wife and three sons survive him.

Army Adams spent a full life in the West and acquired a wide and varied experience in mining, milling, and construction. He had worked for the Liberty Bell Gold Mining and Milling Co., the old Taylor Foundry and Machine Works, United Comstock, Pacific Gas and Electric Co., Mazapil Copper, Deep Creek Placer, Porcupine Mining Co., and the Idaho-Maryland Mines Corp. In 1940 he joined the Poverty Hill Partnership on which operations were suspended in 1942 by Order L-208.

Army Adams had a fund of stories and was one of the most entertaining of men. His resourcefulness expressed itself in his interesting recounting of his experiences. Early in his career he wrote several western stories which were published. Army Adams could be as rough and tough as men come or he could be as gentle as a lamb. He was a keen student of human nature and became an expert judge of men. Men liked to work with Army; though he was a severe taskmaster, they knew him to be fair and just. He was a man of highest mental and moral integrity and he will ever serve as an inspiration to those who knew and loved him.

## Necrology

| Date Elected | Name | Date of Death |
|---|---|---|
| 1928 | Walter B. Congdon | Oct. 20, 1949 |
| 1937 | W. J. Felber | Mar. 18, 1949 |
| 1923 | S. R. Guggenheim | Nov. 3, 1949 |
| 1926 | Thomas K. Knox | Mar. 7, 1949 |
| 1924 | Frank E. Lee | Oct. 19, 1949 |
| 1944 | C. Hubert Lenhart | Oct. 18, 1949 |
| 1901 | Archibald Little | June. 24, 1948 |
| 1897 | John W. Mercer | Oct. 18, 1949 |
| 1948 | Earl H. Moffett | Unknown |

**Arno S. Winther** (Member 1914), former general manager of the Miami Copper Co., is dead. His eminent leadership, friendship, and wise counsel were enjoyed and appreciated by all mining men, from the highest to the lowest, with whom he came in contact. Mr. Winther studied mining engineering at the University of Minnesota and first put his education to work at the Silver King Mining Co. In 1904 he was working for Cerro de Pasco, returning to Utah six years later with the Utah Consolidated Mining Co. He was with United Comstock, California Zinc, Rawley Mines, and Anna Beaver Mines, before taking off for Africa and the N'Kana Mine. By 1936 he was back in the States with Miami Copper.

Arno S. Winther

**Zar T. Crittenden** (Member 1914), plant metallurgist with the Pontiac Motor Car Division of General Motors, died March 25 in Detroit. After getting his degree from the Montana State School of Mines in 1913 he went to sampling and assaying for the Phillipsburg Mining Co. From Montana he moved on to the Beaver Lake mining district of Saskatchewan and then to Manitoba to work for the Flin Flon Exploration Co. By 1919 he was south of the border again, associated with the Oakland Motor Car Co. in Pontiac, Mich., as assistant metallurgist. By 1936 he was plant metallurgist of the Pontiac Motor Car Division of GM.

**Herbert Chester Greer** (Member 1903), president of the Preston County Coke Co., Cascade, W. Va., died in August 1948. Upon graduation from MIT he worked with the Tennessee Coal and Iron Co. as a steel melter in the open-hearth steel department. In 1903 he was manager of the coal and coke department of La Belle Iron Works in Steubenville, Ohio. He owned the Greer Limestone Co. in addition to his work as president of Preston County Coke Co.

**Harry Davenport** (Member 1946), superintendent of mines for the Warren Foundry & Pipe Co., Wharton, N. J., is dead. Mr. Davenport was born in Milton, N. J., in 1889, and lived and worked in that state all his life. At 24 he was superintendent of milling and concentration at the Mt. Hope Mines and became superintendent of mines of the Warren Foundry in 1942.

**James Dyer Jones** (Member 1917), vice-president in charge of engineering for H. A. Brassert & Co., New York City, is dead. Mr. Jones started life in Pittsburgh in 1881, filled his first job there. In 1907 he went to Duluth to work for the Minnesota Steel Co., was with the M. H. Treadwell Co., and then moved to Sault Ste. Marie as assistant chief engineer of the Algoma Steel Co., eventually becoming vice-president and general manager. In 1935 he was in Youngstown, Ohio, as chief engineer for Youngstown Sheet and Tube.

**John Henry Gill Monypenny** (Member 1930), metallurgist for Brown, Bayley's Steel Works, Sheffield, England, died early this year. Mr. Monypenny was born at Sheffield in 1885, went to University College there and had worked for Brown, Bayley's since his graduation in 1904. He was the author of "Stainless Iron and Steel," published in 1926, as well as various technical papers.

**Sidney Lavern Palmer** (Member 1921), metallurgist for the Federated Metals Division of American Smelting and Refining, died May 9. He began his association with American Smelting in 1915, doing engineering work along metallurgical lines at the various smelters and coal mines of the Company in Colorado. Three years later he was in charge of all engineering work and mechanical operations at the Arkansas Valley plant. Since then he had worked for the Company in Colorado and California. Mr. Palmer was born in Ottawa, Ill., in 1883 and received his B.S. degree from Kansas State. For five years he was principal of the high school at Hutchinson, Kans., and then joined AS&R. He developed a number of new metallurgical processes and was instrumental in obtaining patents on these processes, one of which was equipment for casting a new type of bar solder which is sold under the trademark castomatic. During the last several years he had been working on the development of wire solder at the Newark plant.

**Robert Covert Patterson** (Member 1928), who had worked with both the U. S. Bureau of Mines and the U. S. Geological Survey, died April 3 in Glendale, Calif. He had been supervisor of oil and gas operations of the

Pacific division of the USGS and deputy supervisor of oil and gas operations in the Rocky Mountain division of the USBM. Mr. Patterson was born in 1887 in Neville Island, Pa., and was graduated from Occidental College. He had worked for the Standard Oil Co. of California and the California State Mining Bureau.

**Rudolph Porter** (Member 1916), former manager of the Federal plant of the American Smelting and Refining Co. at Alton, Ill., died on July 10. He was born at Cincinnati, Ohio, in 1873. He started work for AS&R at the Pueblo plant and then went to Federal, Ill., as manager of the Federal Lead Co.

# Proposed for Membership

*Total AIME membership on Oct. 31, 1949, was 16,030; in addition 4413 Student Associates were enrolled.*

*ADMISSIONS COMMITTEE*

*James L. Head, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, T. B. Counselman, Ivan A. Given, Robert L. Hallett, Richard D. Mollison, and John Sherman.*

*Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's Office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.*

*In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.*

**ARIZONA**

**Ajo**—RHOADES, RICHARD EVERETT. (C/S—S-J). RICKARD, FORREST ROBERT. (C/S—J-M).
**Phoenix** — RODRIGUEZ, ERNEST R. (C/S—J-M).
TUNNELL, HERBERT R., JR. (C/S—J-M).

**ARKANSAS**

**Magnolia** — CORBY, WILLIAM ROBERT. (C/S—S-J). TURNER, VERNON JAY. (R, C/S—S-M).
**Mountain Home**—WHITLA, RAYMOND E. (C/S—J-M).

**CALIFORNIA**

**Alhambra**—LAIRD, EDWARD ARTHUR. (C/S—S-J).
**Bellflower** — MORROW, THOMAS B. (C/S—J-AM).
**Berkeley** — CHESTERMAN, CHARLES W. (M). WATSON, WILLIAM IRION. (C/S—J-M).
**Hermosa Beach**—LOW, CEDRIC HERBERT. (AM).
**La Jolla**—WARE, JOHN ALLEN, JR. (C/S—S-J).
**Long Beach**—NISSEN, HAROLD EMIL. (C/S—J-M). WADE, FRANKLIN RUSSELL. (C/S—J-M).
**Los Angeles**—ALPERT, LOUIS DAVID. (C/S — J-AM). ANDERSON, ROBERT EDWIN. (C/S — J-M). CHAMBERS, LAWRENCE SHINER. (M) EASTIN, BERTRAND PAUL. (M). HOCHMANN, LOUIS S. (C/S—S-J). KAESS, JAMES DONALD. (R, C/S—S-M). LIEDHOLM, CLARENCE CARLTON. (C/S—J-M).
**Placentia**—KLOTZ, JAMES ALLEN. (J).
**Sacramento**—SKEEHAN, STANLEY S. (C/S—J-AM).
**San Bruno**—DUNCAN, WILLIAM ROY. (C/S—S-J).
**South Gate**—WEBB, BYRON KENDALL. (R, C/S—J-M).
**South Pasadena**—RICHARDSON, ROBERT LLOYD. (C/S—S-J).
**South San Francisco**—ENDERLIN, CALVIN CHARLES. (C/S—S-J).
**Torrance**—FORKUM, CARL (M).

**COLORADO**

**Broomfield** — PARKER, CHARLES OWEN. (M).
**Colorado Springs**—PEARL, RICHARD MAXWELL. (C/S—S-M).
**Craig**—RHEA, JOHN WILLIAM, JR. (R, C/S—S-M).
**Denver**—LINK, GEORGE HICKS. (J).
**Leadville** — NEWLOVE, MARLIN EDGAR. (R, C/S—J-M).
**Rangely**—WANNER, JOHN JAY. (J).

**CONNECTICUT**

**Norwalk**—LYSOBEY, WILLIAM ROBERT. (AM).
**South Glastonbury**—TAFT, BARRETT LORADO. (C/S—J-M).

**DELAWARE**

**Wilmington** — EMERY, BYRON MATHEW. (C/S — S-J). RADTKE, SCHRADE FRED. (M).

**FLORIDA**

**Mulberry** — HEWETT, LOUIS FRANKLIN. (M).
**St. Augustine**—LITTLE, ARCHIBALD. (R—M).

**IDAHO**

**Shelley**—STANIX, S. ANTHONY. (C/S—S-J).

**ILLINOIS**

**Aurora**—GROLL, KENNETH REUBEN. (C/S—J-M).
**Chicago**—AuBUCHON, EDWARD LEROY. (C/S—S-J). CORDES, JOHN ALLEN, JR. (C/S—S-J). FRIEDMAN, ISAAC W. (C/S—J-M). JOHNSEN, STANLEY FRANCIS. (C/S—S-J). LEVER, EDWARD CARL. (C/S—S-J). UTTERBACK, GENE HYATT. (M).
**Danville**—ALPERS, ELBERT EDMUND. (C/S—S-J).
**Elgin**—McGAUGHEY, RAYMOND LEO (C/S—S-J).
**Hillsboro**—WAMPLER, HAROLD RAY. (C/S—J-M).
**Lake Forest**—INTO, A. NORMAN. (M).
**Robinson** — HOELSCHER, JAMES W. (C/S—S-J).
**Washington** — OBERLE, THEODORE LORING. (C/S—J-M).

**INDIANA**

**Bloomington**—DEISS, CHARLES FREDERICK. (M).
**Gary**—PURCELL, STEPHEN McCABE. (C/S—J-M).
**Notre Dame** — LEMENT, BERNARD SAMUEL. (C/S—J-AM).
**Valparaiso**—BOEHME, HAROLD CLAYTON. (J).

**IOWA**

**Keokuk** — OTHMER, LESLIE EARL. (R, C/S—AM-M).

**KANSAS**

**Chase**—AARING, FLOYD DANIEL. (C/S—S-J).
**Ellis** — RENNING, JOHN ALFRED. (C/S—J-M).

**LOUISIANA**

**Monroe** — LEE, JOSEPH L. (M).
**New Orleans**—CREWS, ROBERT NELSON. (AM).
**Shreveport** — BEST, WILLIAM CLAYTON. (C/S—J-M). McNEIL, LAURENCE ALEXANDER. (J). PATTERSON, BENJAMIN FRANKLIN, JR. (C/S—J-M).
**Vinton**—DAWSON, ARCH. (M).
**Vivian**—ELLIS, WILLIAM FREDERICK. (C/S—S-J).

**MARYLAND**

**Silver Spring** — HOPKINS, GEORGE RANDOLPH. (M).

**MASSACHUSETTS**

**Cambridge**—BECKER, J. J. (J).
**Melrose** — BRAHAM, MARTIN BERNARD. (C/S—J-M).

**MICHIGAN**

**Detroit**—BENS, FREDERICK PETER. (C/S—J-M).
**Ironwood**—HOWBERT, JOHN CHARLES. (C/S—S-J).
**Ishpeming** — FISHER, WARREN EDWARD. (C/S—J-M). SUMNER, JOHN STEWART. (C/S—S-J).
**Wakefield**—WALKER, THOMAS. (C/S—S-J).

**MINNESOTA**

**Duluth**—WINN, GEORGE S. (M).
**Hayfield** — LIVINGSTON, JEAN BURTON. (C/S—S-J).
**Hibbing**—ALTHOUSE, JOHN GIVENS. (J). SIMON, ROBERT EDWARD. (C/S—S-J). WHALEY, HENRY PFEFFLE. (C/S—S-J).
**St. James** — GROSS, JOSEPH RAYMOND. (C/S—S-J).

**MISSOURI**

**St. Louis**—FIELDS, LESTER E. (J).

**MONTANA**

**Butte**—BROWN, ALAN DAVID. (C/S—S-J). GRUNENFELDER, J. GEORGE. (R, C/S—J-M). ROBERTSON, FORBES SMITH. (C/S — J-M). RYAN, MARGARET ANN. (C/S—S-J).
**Helena**—BAARSON, ROBERT EUGENE. (C/S—S-J).
**Helmville**—STOUT, KOEHLER SHERIDAN. (C/S—S-J).

**NEVADA**

**Reno** — GRUTT, EUGENE WADSWORTH, JR., (C/S—J-M). HORTON, ROBERT C. (C/S—S-J).
**Ruth** — BAKEWELL, ALAN AVERIL, JR. (C/S—J-M).

**NEW HAMPSHIRE**

**Center Harbor**—DAVISSON, ALAN TUTTLE. (C/S—S-J).

**NEW JERSEY**

**Jersey City** — THOMPSON, RICHARD HULL. (C/S—S-J).
**Matawan**—VOGEL, FERDINAND LINCOLN, JR. (C/S—S-J).
**Metuchen** — CROCKETT, JOHN MORTON. (C/S—J-M).
**Phillipsburg**—MORRISON, GEORGE WILBUR. (M).
**Ridgewood**—THORNLEY, EDWARD WILLIAMS. (AM).
**Tenafly** — VAUGHAN, ROYAL WORTH. (AM).
**West Englewood** — HARSHBERGER. ROBERT PERRINE. (M).
**Westfield**—ALLEN, FORREST EUGENE. (M).

**NEW MEXICO**

**Hobbs**—RANDOLPH, WILLIAM. (C/S—S-J).
**Jal**—BARRETT, JEAN MARTIN. (C/S—S-J).
**Silver City**—DESVAUX, JACK V. (R, C/S—S-M).
**Socorro**—SMITH, CLAY TAYLOR. (C/S—J-M).

**NEW YORK**

**Baldwin**—CARTER, CALVIN B. (M).
**Bayside**—ROSE, FRED DAVID. (C/S—S-J).
**Bronxville** — BRICE, JOHN W. (M).
**Brooklyn**—MERRITT, PHILLIP LEONIDAS. (M). RUZICKA, JOHN. (C/S—J-M).
**Crestwood** — TOWER, HORACE LINWOOD. (M).
**Flushing** — BRUNSTETTER, DONALD RAY. (J).
**Forest Hills** — CAYARD, PAUL CHARLES. (AM).
**Garden City**—LEE W. J. (AM).
**Glen Head** — RISING, ALBERT EDWARD, JR. (C/S—J-M).
**Great Neck** — JEFFREY, FREDERICK R. (AM).
**New York**—ALLAN, ROY CARSON. (M). DAMP, RALPH E. (M). GOLSON, GEORGE ALBERT. (C/S—J-AM). MACAUL, ROBERT THOMAS. (C/S—S-J). OVERBECK, ROBERT STEVENS. (C/S—J-M). PALTY, ADOLPH EDWARD. (J). STRAUS, OSCAR S. (AM).

**Schenectady** — HOWE, JOHN PERRY. (M). NISBET, JAMES DOUGLAS. (AM). PUGH, JOHN WILLIAM. (C/S—S-J). TURNBULL, DAVID. (AM).
**Star Lake**—CRUMP, ROBERT M. (R, C/S—J-M).
**Suffern** — BARRON, WILLIAM MARSHALL. (C/S—S-J).
**Troy** — EBELING, DOLPH GEORGE PHILIPPI. (M).
**White Plains** — KOPECKI, ERNEST STEPHEN. (C/S—J-M).

**NORTH CAROLINA**
**Asheville**—VAN HORN, EARL CARLTON. (C/S—J-M).

**OHIO**
**Barnesville**—GRIMSLEY, JOHN DONALD. (C/S—S-J).
**Columbus**—BAKLANOFF, NICOLAS WLADIMIR. (M).
**Dayton**—SCHNEBLE, A. WILLIAM. (C/S—J-M).
**Mansfield**—SANFORD, JUSTIN H. (AM).
**Zanesville**—CHILDRESS, ALBERT ALLISON. (M). COULSON, FRANK. (M). LINCOLN, RICHARD V. B. (M).

**OKLAHOMA**
**Bartlesville**—POWELL, JOHN PHILIP. (C/S—J-M). WILSON, CONNIE LEE. (J).
**Duncan** — TAPPER WILFRED. (M).
**Miami** — KRISHNASWAMY, RAMANATHA. (C/S—S-J).
**Norman** — COBBS, JAMES HAROLD (C/S—S-J).
**Oklahoma City**—BEEBE, BYRON WARREN. (M). LOWE, ROBERT MONROE. (C/S—S-J). RALPH, RUSSELL GLENN. (M).
**Tulsa** — HULINGS, NORMAN McDERMOTT, JR. (J). NIELSEN, EMERY H. (M).
**Velma**—BOUSFIELD, JOHN CHANNING. (C/S—S-J).
**Wewoka** — MASSAD, ALEXANDER HAMILTON. (R, C/S—S-J).

**OREGON**
**Mill City**—JENSEN, NORMAN CURTIS. (C/S—S-AM).
**Portland**—DEMPSTER, REGINALD CHARLES. (M).

**PENNSYLVANIA**
**Bethlehem** — GUIDER, JAMES WALTER. (C/S—J-M).
**Ellsworth** — BURNS, FRANK ALOYSIOUS. (C/S—S-J).
**Forty Fort** — JAMES HERBERT MORRIS. (M).
**Franklin**—MULOCK, RICHARD BUCKLES. (C/S—J-M).
**Harrisburg**—STEPHENSON, ROBERT CHARLES. (C/S—J.M).
**Hopwood**—SHOTT, ORVILLE ORA. (R, C/S—S-AM).
**Kingston** — EDWARDS, MYLES WILLIAM. (M).
**Johnstown**—CUNNINGHAM, WILLIAM ROY. (M).
**Manor** — BEAMER, PAUL WILLIAM. (C/S—S-J).
**Masontown** — GIROD, JAMES BERTHOLDE. (C/S—S-J).
**New Brighton** — WEHN, JOHN GIRT. (M).
**New Kensington**—LYLE, JOHN PAUL, JR. (R, C/S—S-J).
**Pittsburgh** — FAIRLEY, ALBERT LANGLEY, JR. (C/S—J-M). HARMON, JOHN PAUL. (C/S—J-M). RATZ, GEORGE ALBERT. (J). RITTER, WAYNE G. (C/S—J-AM).
**Pottsville** — CRUM, STANLEY EDWARD. (M).
**Scranton**—LEE, EDWARD JAMES. (C/S—S-J).
**Sewickley** — BRASSERT, CHARLES ALEXANDER. (M).
**Uniontown** — REED, FREDERICK JONES. (M). STACY, RICHARD HAROLD. (C/S—J-M). WERFT, AUGUST R. (M).
**Vandergrift**—WILDE, RICHARD ARNOLD. (C/S—J-M).
**West Brownsville** — KRESE, JAMES MARTIN. (C/S—J-M).
**White Haven**—JENKINS, CARL S. (M).

**SOUTH DAKOTA**
**Belle Fourche** — MARSHALL, LAWRENCE KILBURN. (C/S—J-M).
**Rapid City** — EVANS, OWEN DANFORTH. (C/S — J-M). TULLIS, EDWARD LANGDON. (C/S—J-M).

**TENNESSEE**
**Columbia** — GUENTHER, WILLIAM FREDERICK, JR. (C/S—J-M).
**Jefferson City** — MILLER, HOWARD WILLIAM. (C/S—J-M).
Oak Ridge — STEPHEN, HANS RICHARD. (C/S—J-M).

**TEXAS**
**Abilene**—REEVES, CARL LYNCH. (M).
**Alice** — HOLLAND, TURNER BOYD. (M).
**Alvin** — PIERCE, VINTON DOUGLAS. (C/S—S-J).
**Amarillo**—SEIBEL, CLIFFORD WINSLOW. (M).
**Austin**—PULS, WILLIAM LEROY. (R, C/S—S-J).
**Beeville**—PRINCE, NOONAN ALBERT. (J).
**Bellaire**—WILLIAMS, CHARLES EDWIN, JR. (AM).
**Breckenridge** — REAUGH, ORLAND HARRY. (M).
**Carthage** — SLEDGE, ALBERT G., JR. (C/S—S-J).
**Corpus Christi**—CULWELL, WARREN DALE. (J).
**Dallas**—HUTCHINSON, CHARLES ANGEVINE, JR. (J). KOCH, HOWARD ALEXANDER. (J). SHEPHERD, GEORGE FREDERICK. (R, C/S—J-M). STEPHENS, RICHARD GERRARD. (C/S—S-J). WARD, THEODORE GARLAND. (C/S—S-J).
**El Campo**—AUBUCHON, PIERRE MARVIN. (J). McARTHUR, ARTHUR A. (C/S—S-J).
**El Paso**—BELL, MARION S. (J).
**Fort Worth**—TAPP, THEODORE LELAND. (M).
**Hawkins**—McLAREN, CORNELIUS FORT, JR. (C/S—J-M).
**Houston** — CLOUD, GOULD HENDERSON. (M). HAMEL, ROGER C., JR. (M). HARTUNG, GEORGE HERMANN. (M). HOLMAN, OSCAR KEITH. (C/S—J-M). LEWIS, RAY C. (M). LOBDELL, WALTER REGINALD. (M). LOCKWOOD, JAMES POTTER. (J). MATTHEWS, CHARLES SEDWICK. (J). ROOF, JACK GLYNDON. (M).
**Kingsville** — SUMAN, RICHARD HARLAN. (C/S—S-J).
**Levelland** — LANE, ROBERT DANIEL (J). RODENBERGER, CHARLES ALVARD. (J). WADLINGTON, WILLIAM HAMILTON. (C/S—S-J).
**Liberty**—PERILLOUX, CHARLES JOSEPH. (J).
**Longview** — FULLER, C. CLARK, JR. (J).
**Lubbock** — JOHNSON, PHILIP. (M).
**Midland**—PATTON, MARK STEEVENS, JR. (C/S—J-M).
**Odessa**—COCANOWER, ROBERT DUNLAVY. (M).
**Sunray**—RABALAIS, MELFORD FRANCIS. (C/S—S-J).
**Yoakum** — WAKE, HERBERT NEIL (C/S—S-J).

**UTAH**
**Bingham** — ALLAN, CHARLES WALLACE. (C/S—S-J).
**Cedar City**—COOK, KENNETH LORIMER. (C/S—J-M).
**Lark**—BINGHAM, CLARENCE P. (R, C/S—S-J).
**Midvale** — HINKS, WARREN HENRY, JR. (C/S—S-J).
**Salt Lake City** — BARBER, CYRIL JAMES. (M). CAREY, GLEN ALBERT. (C/S—S-J). EVERETT, FLOYD DAVIS. (C/S—J-M).
**Tooele**—TOWNSEND, BYRON E. (M).

**VIRGINIA**
**South Hill**—SUTTON, HAROLD LEE. (C/S—J-AM).

**WASHINGTON**
**Seattle** — BRUGMAN, JOSEPH JOHN. (C/S—J-M). STOLL, WALTER CLERIOUS. (C/S—J-M).
**Spokane** — ZOLDOK, STEPHEN WILLIAM. (C/S—J-M).
**Tacoma** — BUTLER, EARL BLUETT. (M). RICHARDSON, FREDERICK WILLIAM. (C/S—S-J).

**WEST VIRGINIA**
**Bluefield**—WALKER, WILLIAM WADE. (M).
**Huntington** — HEBDEN, EDWARD H. (M). HASKELL, JAMES BLISS. (M).
**Logan**—SWANGO, ARBERRY BERYL. (J).
**Monaville**—LOPES, CARLOS JOSE. (M).
**Mount Hope**—McINTIRE, SAMUEL THOMAS. (M).
**Neills** — BARTONY, HENRY ERNEST (C/S—S-J).
**Parkersburg** — JOHNSTON, HOWARD FEIGHNER. (C/S—J-M).
**Pineville** — REDYARD, JESSE. (AM).

**WISCONSIN**
**Hales Corners**—SNAVELY, J. W. (M).
**Milwaukee**—BRONKALA, WILLIAM JENNINGS. (C/S—S-J).
**Shorewood** — HEGGINS, GEORGE W. (C/S—J-M).

**WYOMING**
**Casper**—RICHARDS, SIDNEY BRUCE. (C/S—J-M). SCHUMACHER, JOHN EARL, JR. (C/S—S-J).
**Cody**—HAAS, GILBERT GEORGE (C/S—J-M). MORTON, LELAND MATTHEWS. (J). PATERSON, JOHN FRUIN. (C/S—J-M).
**Grass Creek** — SPIELES, EARL LOYD. (C/S—S-J). LANDER, ROBERT BARTLETT. (J).

**ALBERTA**
**Calgary**—McPHERSON, WILLIAM JOHN. (C/S—S-M).

**BRITISH COLUMBIA**
**Allenby**—TAIT, ROBERT JOHN COMPTON. (C/S—S-AM).
**Vancouver**—GUNNING, HENRY C. (M).

**ONTARIO**
**Holtyre**—CAYLOR, RUSSELL D. (C/S—J-M).
**Madsen** — VAN LOON, LESLIE HART. (C/S—J-M).
**Port Colborne** — CORDNER, T. (M).

**GUERRERO**
**Mexcala** — CROSBY, ALLEN FOSTER. (C/S—J-M).

**QUERETARO**
**Cadereyta** — FAULKNER, JAMES E. JR. (C/S—S-J).

**NICARAGUA**
**Managua**—BATH, KENNETH ARTHUR. (C/S—S-J).

**BOLIVIA**
**Oruro** — ANTEZANA, CARLOS JORGE. (C/S—S-AM).

**BRAZIL**
**Rio de Janeiro**—ODDONE, DECIO SAVERIO. (C/S—J-M).

**CHILE**
**Rancagua**—SWAIN, ROBERT LOCHE. (C/S—S-J).

**COLOMBIA**
**Antioquia** — SCHOU, HANS HELGE. (C/S—J-M).

**VENEZUELA**
**Barcelona** — HUIE, JAMES POWELL. (AM). ROBERTS, CHARLES C. (C/S—J-M). WILSON, LEJEUNE. (C/S—S-J).

**ENGLAND**
**Cumberland** — YOUNG, JOHN D. (J).

**FRANCE**
**Paris**—CALLEYA, GEORGES XAVIER. (M). JACQUET, PIERRE ARMAND. (M). PETIT, DANIEL. (M).

**SWEDEN**
**Huskvarna**—KOUKKOLA, KALEVI VILJAM. (J).

**TRANSVAAL**
**Johannesburg** — ENSLIN, JOHANNES STEPHENUS. (C/S—S-M). MARTINCEVIC, NICHOLAS. (C/S—J-M).

**FEDERATED MALAY STATES**
**Kuala Lumpur** — EDMONDS, HAROLD JOSEPH. (C/S—AM-M).

**INDIA**
**Kolar Gold Field**—NARAYANA RAO, C. E. (C/S—J-AM).
**Oorgaum**—SUBRAMANYAM, MATHURMUTHU. (C/S—J-M).

**PHILIPPINE ISLANDS**
**Surigao** — MERWIN, ROLAND WINFIELD. (M).

# WAVE FORCES COMPUTED FOR A TYPICAL OFFSHORE DRILLING SITE

**PAUL L. HORRER,** SCRIPPS INSTITUTION OF OCEANOGRAPHY, LA JOLLA, CALIFORNIA

## ABSTRACT

Costly damage by severe wave attack to many engineering structures has illustrated the need for a consideration of the nature of wave action in plans for offshore drilling operations. Using wave data it is possible to answer questions pertaining to engineering problems such as platform elevation, structure orientation, and expected wave forces. For locations where wave records are not available a technique can be used to obtain information about wave characteristics from past meteorological data and near shore submarine topography. Forces exerted on structures by waves may be divided into four parts. A completed study is given in which frequencies of various wave heights and maximum frictional drag forces are computed for a typical offshore drilling site.

## INTRODUCTION

Waves of tremendous proportions accompanying hurricane winds crash against breakwaters and other offshore structures causing untold damages. Wave forces exerted on structures at these times are enormous, as shown by past records of incidents where massive portions of breakwaters have been broken off and moved by waves. On other similar occasions, whole structures have been unloosed and smashed or floated away. These incidents, which seem almost incredible, serve to illustrate the great amount of energy contained in large waves, and to show that this energy results in powerful forces destructive to offshore installations which are not designed sufficiently strong to withstand wave attack.

In the past the expected frequencies of waves having various characteristics have rarely been considered in the design of structure affected by wave action. As a result, many structures have failed to accomplish the purpose for which they were designed or have collapsed under wave attack. Others have been constructed to withstand greater wave energy than is ever encountered, with resulting waste of material and construction time.

In this study an analysis is made of the frequencies of waves having different characteristics which affect the plans for offshore drilling installations. After such an analysis the erection of these structures can proceed with less risk involved and with more efficiency and economy.

## ENGINEERING ASPECTS

In the offshore drilling program wave forces play an extremely important part in design and construction of drilling rigs in shallow water. The design of a platform or other structure from which drilling equipment is operated is critical, because any damage to the platform may endanger personnel and result in complete loss of equipment. Since a platform built too close to the water would be battered by breakers, and one built unnecessarily high would involve undue expense, it is necessary to know the most desirable elevation at which the platform should be erected. This is only one of many questions about structural planning which can be answered using existing technique for determining wave characteristics.

The purpose of efficient design for the portions of many types of offshore structures which are acted upon by wave forces is the same as that of all designs which deal with frictional forces of a fluid on a solid. For these structures the problem is comparable to that encountered by undersea craft moving through water, except that in the case of a fixed structure the force is produced by the water moving past the model. For off shore sructures which are extremely rigid the frictional forces may be nearly negligible compared with the impact or shock forces imparted by breaking waves. In all cases the better design is that which offers the least resistance to the opposing forces.

From a consideration of wave forces, each drilling structure varies in efficiency depending upon the type and amount of superstructure in contact with the waves. For example, round piling and bracing offer less resistance to wave forces than do I-shaped ones. All network superstructure such as cross bracing should be kept to a minimum and at as low an elevation as possible, so that it will not expecience the pressure exerted at the tops of breaking waves. Models of proposed structures can be tested in wave tanks and in the field to ascertain the efficiency of specific designs.

Past experience in beach and shoreline engineering has shown that, although changes in the topography of the bottom very near shore do not seem to be occurring, the natural forces involved may be in a delicate balance such that a static state exists. Interruptions of any of these natural forces by erecting offshore structures are likely to cause undesirable effects. Changes in beach profile result partly from sediment being brought into suspension by the orbital motion of waves and partly from the transport of sediment by longshore currents. With the erection of an offshore structure and consequent change in the combined effects of these two forces, unfavorable deposition upon, or erosion of, the bottom at the site may occur. Therefore, combination wave and current studies are essential for the solution of problems involved in the design of most marine structures.

## TECHNIQUE FOR OBTAINING WAVE INFORMATION

In determining the probable effect of wave action on an offshore drilling structure, it is first necessary to know the usual frequencies of certain wave types for the given location. A technique[1,8,9,11,12] has been developed which provides a means for obtaining information about wave characteristics in the

Manuscript received at office of the Petroleum Branch August 12, 1949. Presented at Branch Fall Meeting, San Antonio, Texas, October 5-7, 1949.

[1] References are given at end of paper.

past using meteorological data and the known submarine topography of the region. The procedure for obtaining this information at a given location involves three steps: the first utilizes past weather maps, which are readily available, for the computation of wave characteristics in deep water; the second determines the modification of these characteristics as the waves travel into shallow water towards shore; the third, using the shallow water wave characteristics, provides the expected frequencies of forces and moments on engineering structures at the proposed location.

## METEOROLOGICAL CONSIDERATIONS

Waves are produced in an area where moderate to strong winds are blowing over the ocean and exerting frictional drag on the water surface. The higher waves result from strong winds when there are relatively large areas over which the winds are blowing. After formation, waves move out of the generating area and proceed with gradually diminishing heights through areas of calm or variable winds until, after traveling hundreds of miles, their heights may become insignificant. It is therefore necessary in computations of waves to consider storms occurring in all parts of the sea or ocean in which the drilling site is located. As an example[8] of wave propagation over great distances, the nature of the surf and character of the beach in some parts of Southern California in summer are largely determined by waves which have traveled from the southern hemisphere.

At any given instant, ocean waves are usually not uniform but have a variety of heights and periods. The procedures for determining the characteristics of waves in deep water which progress toward a given location immediately offshore have been devised so as to give the average height and period of the highest one-third of all waves present. An analysis[10] of Pacific Coast wave records indicates that the average height of the highest 10 per cent of the waves is equal to 1.29 times the height of the highest one-third. The maximum highest wave measured each day has a height which is equal to 1.87 times the average height of the highest one-third. The computations made in this study are completed for both the highest 10 per cent and the maximum highest waves which are expected.

## EFFECT OF IRREGULAR BOTTOM NEAR SHORE

As waves enter shallow water they are transformed under the influence of bottom topography. Refraction occurs when the wave crest advances over an uneven bottom. The portions of the wave which are in deeper water have a greater velocity than those in shallow water. This causes a bending of the crest. Under such circumstances the wave energy is concentrated in some shore areas and reduced in others. Consequently, wave height may be either increased or decreased as waves travel into shallow water towards the breaker zone.

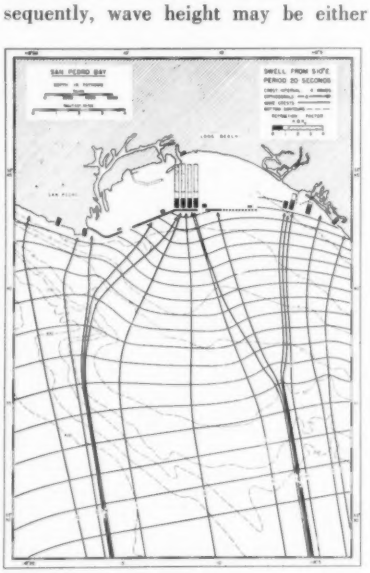


FIG. 1 — A SAMPLE REFRACTION DIAGRAM ILLUSTRATING CONVERGENCE AND DIVERGENCE OF WAVE ENERGY DUE TO REFRACTION OVER IRREGULAR BOTTOM.

The drawing[9] of refraction diagrams is a portion of the technique essential to the accurate computation of wave forces in shallow water. In Fig. 1 is shown a sample refraction diagram[5] illustrating convergence and divergence of wave energy due to refraction over irregular bottom. The magnitude of the refraction factors, to which the wave heights are directly proportional, is indicated by the length of the bars shown in Fig. 1. The wave heights, as determined by these refraction factors, vary from 20 per cent to 350 per cent of the heights the same waves would have if no refraction occurred.

Refraction diagrams are useful in determining the best location for a drilling site. The importance of selecting a location where convergence does not occur cannot be over emphasized.

## NATURE OF WAVE FORCES

In shallow water the maximum wave height at any depth is that of a wave whose characteristics are such that it breaks at that depth. Although the total energy of a wave is slightly reduced as it comes into water shallow enough to alter its form, a greater portion of its total energy then lies above still water level and moves forward with the wave form. Consequently a breaker produces a much greater stress on structures than would a wave of equal height in deep water. The frequency of breakers of different kinds at a given location depends upon the

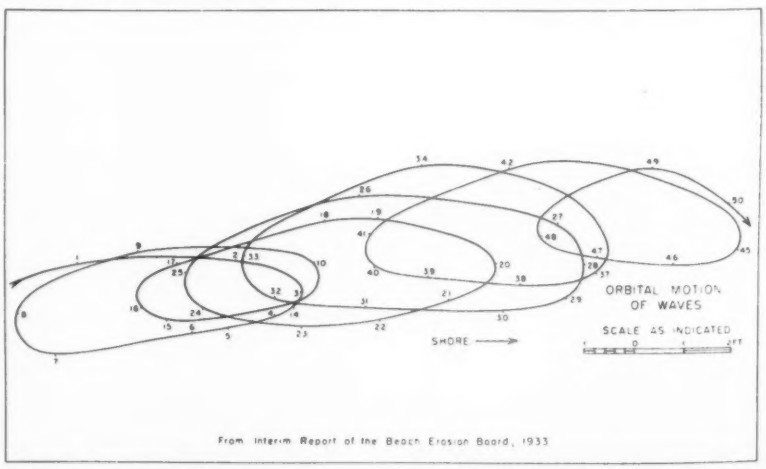



FIG. 2 — ORBITAL MOTION OF WAVES 5 FT TO 7 FT BELOW SURFACE OF WATER. TIME INTERVAL TWO SECONDS FOR EACH CONSECUTIVE NUMBER.

frequency of waves of different heights in deep water offshore, refraction characteristics over shallow bottom near the location, and the depth of water at the location.

For all but very short period waves a linear relationship exists between the height of breakers and the depth of water in which breaking waves occur. The depth at a drilling site may vary due to regular astronomical tides and also due to storm tides which result from piling up water along the coast by wave transport and transport due to wind stress on the sea surface. For this reason at a given location there are a number of different breaker heights possible, of which the greatest may occur only in connection with intense storms. Rather large depth changes at a given location are especially characteristic in the case of hurricanes, and special consideration must be given to the associated problems in the Gulf of Mexico where hurricane waves are not infrequent.

The forces exerted by waves on structures in or near the breaker zone are due to (1) acceleration, (2) friction, (3) impact, and (4) hydrostatic head.

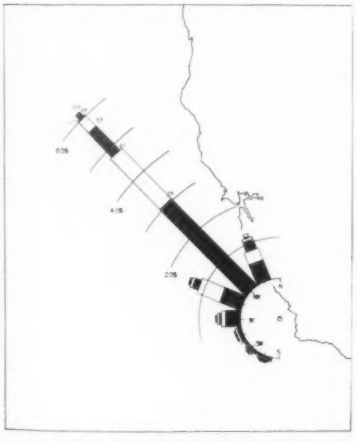


FIG. 3 — WAVE HEIGHT AND DIRECTION IN DEEP WATER.

It has been shown[6,7] that the acceleration force and frictional drag force are related to the particle or orbital motion of the waves. The nature of the particle movement in waves has been studied[3] using motion pictures of a float in a wave, and a picture is shown in Fig. 2. The dynamic pressures exerted by the tops of breaking waves represent the greatest frictional drag to which structures may be subjected by wave action because at the very crests of breaking waves the orbital velocity is at a maximum. The acceleration force is a maximum prior to the arrival of the crest.

The magnitude of each of the four types of force may vary depending upon the design characeristics of a given structure as well as the wave characteristics. For example, an analysis[5] of breakwater damage indicated that a breakwater erected on a random rubble foundation may be less subject to damage by wave impact or shock force than a breakwater built upon a more rigid cut stone foundation. Wave tank studies[2] show that impact forces of extremely short duration due to waves breaking on certain structures may be at least one order of magnitude greater than forces due to friction and acceleration. The pressure due to hydrostatic head is of importance only in the case of structures such as breakwaters where a water level difference is maintained by waves.

## STUDY FOR TYPICAL DRILLING SITE

For illustrative purposes an application of the entire wave computation technique has been made for a location off the coast of California at 35°N latitude in 20 feet depth, mean low water. Fig. 3 shows statistics on wave height and direction in deep water calculated[10] for the three years 1936 to 1938. In deep water it can be seen that the greater percentage of higher waves is from the northwest. These statistics shown in Fig. 3 provide the basis upon which the wave forces at the site are computed.

In order to examine the effects of the bottom on waves approaching the sample drilling site, 17 refraction diagrams were drawn for waves of different directions and periods. Fig. 4 summarizes the refraction effects at the drilling site for all of the 17 individual diagrams. It shows what portions of deep water wave height remain after refraction for waves of different periods and deep water directions. Since no portion shown is greater than unity, it can be seen that little or no convergence is present at this location. A region of approximately no change in wave height due to refraction exists for directions in the westerly quadrant. As the directions change, either toward the north or toward the south, the waves are seen to diverge in traveling over the shallow depths adjacent to the coast. Using the frequencies of waves greater than a given height at the site, after the shallow water corrections have been applied, it is possible to compute a weighted average of the refraction factors. This can be done for the site and nearby areas to determine whether waves at the site will be larger or smaller on the average than waves in areas adjacent to the site.

Fig. 5 summarizes the directions of wave crest advance at the site for waves

## TABLE I

*Height and Period Frequencies (in days) at Site for Highest 10 Per Cent of Waves (Total Time 3 Years)*

*H (Feet)*

| T(seconds) | Less Than 2 ft. | 2—4 | 4—6 | 6—8 | 8—10 | 10—12½ | 12½—15 | 15—17½ | 17½—19½ (Breakers) | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 2— 4 | 73.6 | 41.7 | .3 | .4 | | | | | | 116.0 |
| 4— 6 | 168.4 | 110.0 | 10.7 | 9.0 | 2.4 | .3 | | | | 300.8 |
| 6— 8 | 83.1 | 59.4 | 25.4 | 15.1 | 7.2 | 2.4 | | | | 192.6 |
| 8—10 | 50.1 | 47.9 | 5.8 | 5.4 | 3.6 | 2.7 | .4 | .5 | .1 | 116.5 |
| 10—12 | 41.8 | 40.3 | 10.9 | 1.0 | 3.4 | .1 | .2 | | .6 | 98.3 |
| 12—14 | 43.4 | 54.5 | .3 | 10.6 | | 2.3 | 1.4 | .8 | .4 | 113.7 |
| 14—16 | 46.8 | 35.5 | 20.6 | 5.6 | | .2 | .2 | | .1 | 109.0 |
| 16—18 | 35.2 | 32.3 | 17.9 | 2.2 | | | | | | 87.6 |
| 18—20 | 18.8 | 12.4 | 5.8 | 1.4 | .1 | | | | .9 | 39.4 |
| Greater than 20 | 3.4 | 2.5 | .2 | .2 | .3 | | | | .1 | 6.7 |
| Total | 564.6 | 436.5 | 97.9 | 50.9 | 17.0 | 8.0 | 2.2 | 1.3 | 2.2 | 1,180.6 |

approaching the site and having any given period and direction in deep water. Wave refraction changes not only the wave height, but changes the direction of wave advance, and the change is such that the wave crests tend to become parallel to the bottom contours as the waves approach shore, thereby decreasing the variability in direction of wave approach at the shore. Fig. 5 shows that the waves at the site have a direction varying from 240° to 300° and that this variation in wave direction is greater for the shorter period waves which are less influenced by the bottom topography than waves of longer period. For the longer period waves the direction varies from about 255° to 290°. The weighted average direction at the site for waves higher than a given value can be determined. This direction can be used in determining the orientation of engineering structures which will offer the least resistance or maximum breakwater action, depending on the purpose for which the engineering structures to be employed.

In Fig. 6 is shown the maximum breaker heights associated with a 25-foot depth (mean high water at site) and the corresponding deep water wave heights for different period waves. Because 25-foot depth provides, on the average, the worst possible breaker conditions at the site unless a storm tide is produced, this depth was used for calculating the wave and breaker heights at the site. In most cases the duration of periods having fairly large waves was greater than the time between high and low tide. Fig. 6 does not include refraction effects. It is noted that change in wave height due to shallowing of the water alone varies considerably with period.

Using the refraction effects shown in Fig. 4 and applying other shallow water corrections, the height and period frequencies in days at the site for the highest 10 per cent of the waves and for the maximum highest waves were calculated and are tabulated in Tables 1 and 2. Data of this type may be used for calculating dimensions of waves to be used in model experiments. After refraction, a rather large proportion of the deep water waves had heights which were less than two feet. Consequently, the number of days in which actual breakers at the site occurred was considerably less than would be expected. Out of the 1180.6 computed days only on 81.6 days were 10 per cent of the waves greater than 6 feet at the site. If only the maximum highest wave is considered, then on 176.4 days were the waves greater than 6 feet. On only 2.2 days were 10 per cent of the waves breaking at the site. On 6.8 days the very highest waves were breaking at the site. These breakers, however, occur with a number of different storms such that there is 100

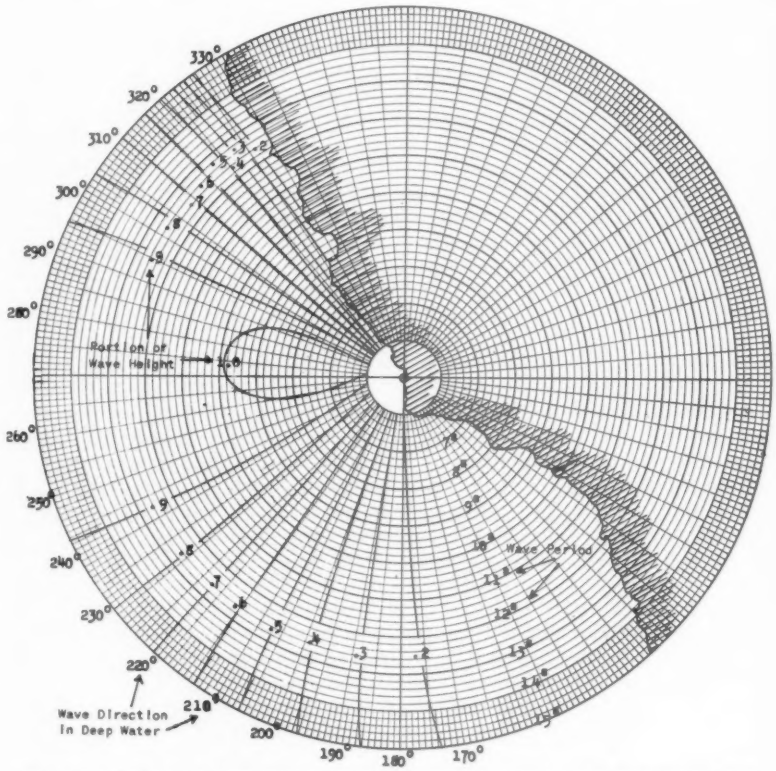



FIG. 4 — PORTION OF DEEP WATER WAVE HEIGHT REMAINING AFTER REFRACTION FOR WAVES OF DIFFERENT PERIODS AND DEEP WATER DIRECTION.

## TABLE II

*Height and Period Frequencies (in days) at site for Maximum Highest Waves (Total Time 3 Years)*

*H (Feet)*

| T(seconds) | Less Than 2 ft. | 2—4 | 4—6 | 6—8 | 8—10 | 10—12½ | 12½—15 | 15—17½ | 17½—19½ (Breakers) | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 2— 4 | 73.2 | 35.2 | 7.8 | .1 | .4 | | | | | 116.7 |
| 4— 6 | 161.4 | 60.0 | 51.5 | 9.7 | 7.1 | 2.3 | 2.4 | .3 | | 294.7 |
| 6— 8 | 61.7 | 43.1 | 38.5 | 24.5 | 3.9 | 11.4 | 8.0 | 1.6 | | 192.7 |
| 8—10 | 49.8 | 31.0 | 17.2 | 5.3 | 5.2 | 7.5 | 3.1 | 2.3 | 1.4 | 122.8 |
| 10—12 | 42.8 | 19.1 | 21.2 | 2.8 | 8.1 | 3.4 | | | .9 | 98.3 |
| 12—14 | 43.0 | 32.9 | 22.1 | .3 | 3.1 | 7.5 | 2.3 | | 2.6 | 113.8 |
| 14—16 | 27.3 | 19.5 | 35.5 | 20.6 | .7 | 3.8 | .2 | | .3 | 107.9 |
| 16—18 | 22.8 | 12.5 | 32.2 | 17.7 | .9 | 1.5 | | | | 87.6 |
| 18—20 | 11.6 | 7.7 | 17.7 | | .4 | 1.0 | | | 1.0 | 39.4 |
| Greater than 20 | 1.5 | 1.9 | 2.5 | .2 | | | | | .6 | 6.7 |
| Total | 495.1 | 262.9 | 246.2 | 81.2 | 29.8 | 38.4 | 16.0 | 4.2 | 6.8 | 1,180.6 |

per cent probability that in any given year breakers whose height is 19.5 feet will be formed at the site. If a storm tide of 5 feet had occurred at the times when the largest waves were present, 23.4 foot breakers could also have been formed at the site.

In Fig. 7 is shown the cumulative per cent frequency of various wave heights greater than 6 feet for both the 10 per cent highest and the maximum highest waves. Because a larger number of the maximum highest waves are associated with the larger wave heights, this curve is more steep for the values of greater height than is the curve for the highest 10 per cent. In computing the wave forces in piling, it has been assumed that it would be desirable to know the forces exerted for various stands of the tide, and also when a storm tide occurred. Therefore, four representative cases have been studied. These cases are tabulated in Table III. Cases 2 and 3 occur frequently as the tide is largely semi-diurnal in character, and Case 2 gives the lowest breakers which could be formed at the site. The maximum horizontal velocities were computed using the solitary wave theory.[5]

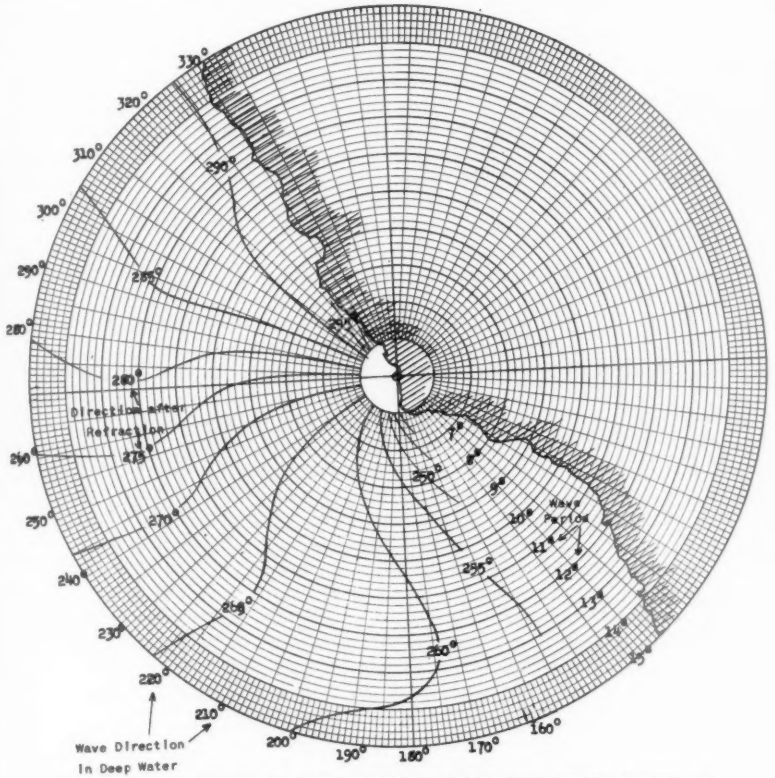



FIG. 5 — WAVE DIRECTION AFTER REFRACTION FOR DEEP WATER WAVES OF DIFFERENT PERIODS AND DIRECTIONS.

## TABLE III

*Representative Cases for Which Maximum Horizontal Dynamic Pressures Due to Frictional Drag Have Been Calculated*

| | Case 1 | Case 2* | Case 3* | Case 4* |
|---|---|---|---|---|
| Sea (water) Level | mean high water | mean low water | mean high water | mean high water and 5′ storm tide |
| Still water depth (feet) | 25 | 20 | 25 | 30 |
| Wave height (feet) | 10.0 | 15.6 | 19.5 | 23.4 |
| Height to crest above bottom (feet) | 32.2 | 31.7 | 39.6 | 47.5 |
| Wave velocity (feet per sec.) | 29.7 | 32.5 | 37.9 | 41.5 |
| Max. Horizontal orbital velocity (feet per sec.) | 10.6 | 32.5 | 37.9 | 41.5 |
| Max. horizontal dynamic pressure due to frictional drag on circular pile (pounds per sq.ft.) | 37 | 344 | 473 | 567 |

*Breakers

Methods for computing forces due to impact and acceleration are not available. However, maximum horizontal dynamic pressures due to frictional drag on circular pile at various elevations above the bottom for these four cases are shown graphically in Fig. 8. For circular pile a drag coefficient of .33 was used in the computations. On a flat plate perpendicular to flow a value of 1.9 should be used such that all pressures in Fig. 8 would be 5.8 times as large for square or I-shaped pile. The total frictional forces on a pile may be obtained by integrating the area to the left of the curves in Fig. 8. The turning moment can be calculated by using the difference between the forces near the top of the curve and that near the bottom. The small pressures of Case 1 are typical of non-breaking waves.

Although forces of acceleration and impact are not shown in Fig. 8 the curves are useful for relative comparison of the effect of wave action from waves having different dimensions.

## CONCLUSIONS

Wave forces play an extremely important part in the design and erection of offshore drilling structures. An adequate technique exists for the determination of expected frequencies of waves having different characteristics from past weather data and the known submarine topography of the region, but methods for computing wave forces are not yet complete. The entire procedure has been illustrated by an example in which wave height frequencies and the frictional forces on circular pile are given. Although the techniques used herein have been described elsewhere, an application of all these techniques to one location has not previously been made generally available.

## ACKNOWLEDGMENT

I wish to express my thanks to Paula M. Horrer for assistance in computations and in preparing Figs. 3-8.

## REFERENCES

1. Arthur, R. S., 1947, "Revised Wave Forecasting Graphs and Procedures," Scripps Institute of Oceanography Wave Report No. 73, 14 pp., 10 plates.
2. Bagnold, R. A., 1939, "Interim Report on Wave-Pressure Research," *Journal Institution of Civil Engineers*, London, v. 12, pp. 202-226.

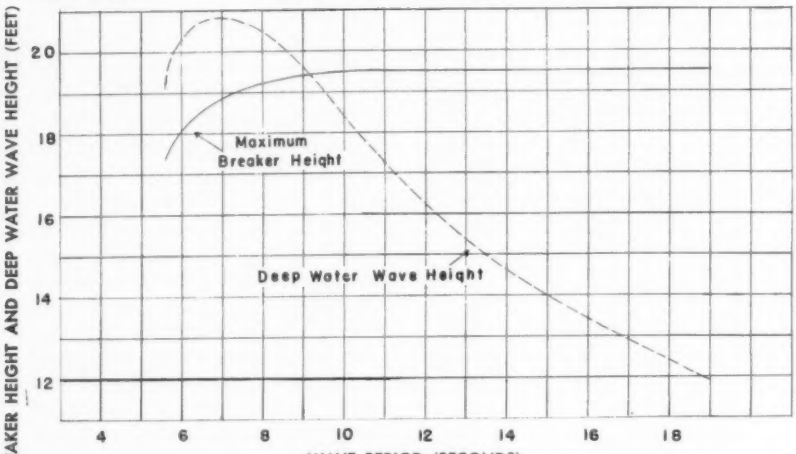



FIG. 6 — MAXIMUM BREAKER HEIGHTS AT 25-FOOT DEPTH AND CORRESPONDING DEEP WATER WAVE HEIGHTS FOR DIFFERENT PERIOD WAVES.

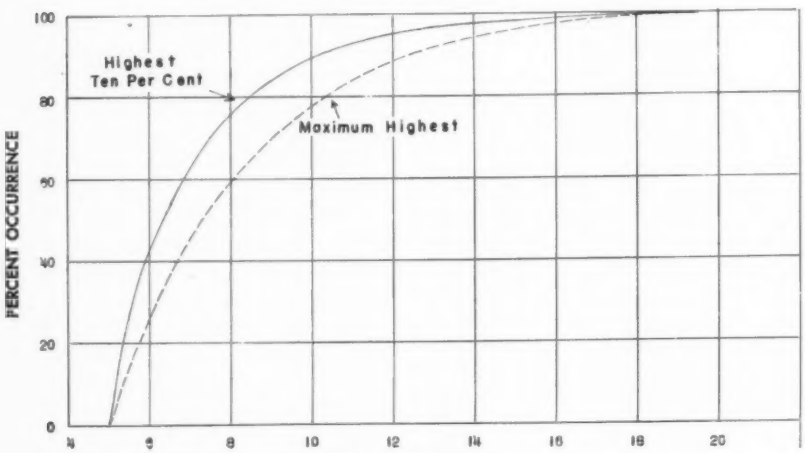



FIG. 7 — CUMULATIVE PERCENTAGE FREQUENCY OF WAVE HEIGHTS FOR HIGHEST TEN PER CENT AND FOR MAXIMUM HIGHEST WAVES WHICH ARE 6 FOOT OR HIGHER AT 25-FT. DEPTH.

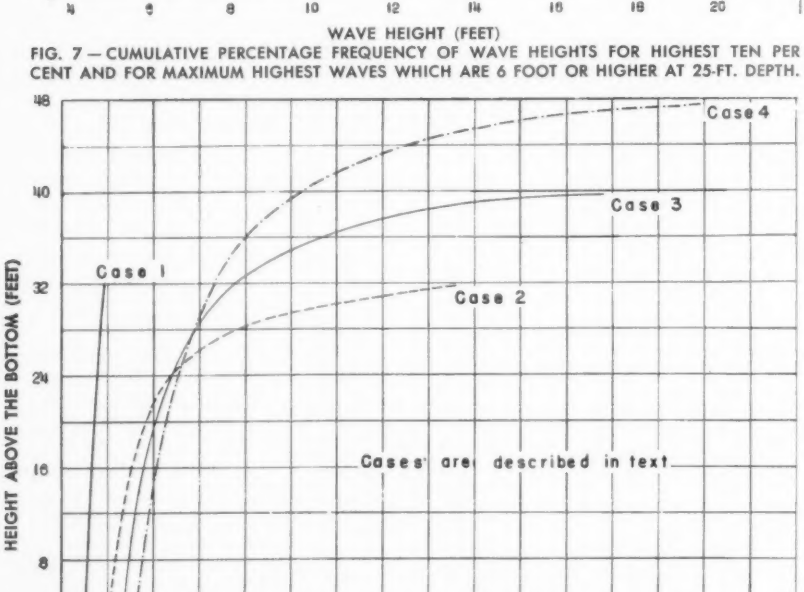



FIG. 8 — MAXIMUM HORIZONTAL DYNAMIC PRESSURES DUE TO FRICTIONAL DRAG EXERTED BY WAVES ON CIRCULAR PILE.


3. Beach Erosion Board, 1933, Interim Report of the Beach Erosion Board, Office of the Chief of Engineers, U. S. Army.
4. Bigelow, H. B., and W. T. Edmondson, 1948, "Wind Waves at Sea, Breakers and Surf," U. S. Hydrographic Office, H. O. Pub. No. 602, 176 pp.
5. Horrer, P. L., 1948, "Southern Hemisphere Swell and Waves from a Tropical Storm at Long Beach, California," Wave Project Report No. 76, Scripps Institution of Oceanography of the Univ. of California, 12 pp.
6. Morison, J. R., O'Brien, M. P., Johnson, J. W., and Schaaf, "The Force Exerted by Surface Waves on Piles", to be published in *Jnl. Petr. Tech.*, AIME.
7. Munk, W. H., 1948, "Wave Action on Structures," Technical Publication No. 2322, *Petr. Tech.*, AIME, 18 pp.
8. Munk, W. H., 1949, "The Solitary Wave Theory and its Application to Surf Problems," Annals of the New York Academy of Sciences 51 (3), pp. 376-424.
9. Munk, W. H., and Traylor, M. E., 1947, Refraction of Ocean Waves. "A Process Linking Underwater Topography to Beach Erosion," *Journal Geology* 55 (1), pp. 1-26.
10. Saur, T., Anderson, R. E., Burt, W. V., and Thompson, W., 1947, "A Statistical Study of Wave Conditions at Five Open Sea Localities Along the California Coast," Wave Project Report No. 68, Scripps Institution of Oceanography of the Univ. of California, 34 pp.
11. Sverdrug, H. U., and Munk, W. H., 1947, "Wind, Sea and Swell: Theory of Relations for Forecasting." U. S. Hydrographic Office, Technical Report No. 1, H. O. Pub. No. 6 pl., 44 pp.
12. U. S. Navy Hydrographic Office, 1945, "Breakers and Surf: Principles in Forecasting," H. O. Pub. 234, 55 pp., 4 plates.
13. Wiegel, R. L., 1949, "An Analysis of Data from Wave Recorders on the Pacific Coast of the United States," Technical Report HE-116-246, Fluid Mechanics Laboratory of the Univ. of California, Berkeley, California, 5 pp.


* * *

# THE APPLICATION OF THE LAPLACE TRANSFORMATION TO FLOW PROBLEMS IN RESERVOIRS

**A. F. VAN EVERDINGEN,** SHELL OIL CO., HOUSTON, AND **W. HURST,** PETROLEUM CONSULTANT, HOUSTON, MEMBERS AIME


## ABSTRACT

For several years the authors have felt the need for a source from which reservoir engineers could obtain fundamental theory and data on the flow of fluids through permeable media in the unsteady state. The data on the unsteady state flow are composed of solutions of the equation

$$\frac{\partial^2 P}{\partial r^2} + \frac{1}{r}\frac{\partial P}{\partial r} = \frac{\partial P}{\partial t}$$

Two sets of solutions of this equation are developed, namely, for "the constant terminal pressure case" and "the constant terminal rate case." In the constant terminal pressure case the pressure at the terminal boundary is lowered by unity at zero time, kept constant thereafter, and the cumulative amount of fluid flowing across the boundary is computed, as a function of the time. In the constant terminal rate case a unit rate of production is made to flow across the terminal boundary (from time zero onward) and the ensuing pressure drop is computed as a function of the time. Considerable effort has been made to compile complete tables from which curves can be constructed for the constant terminal pressure and constant terminal rate cases, both for finite and infinite reservoirs. These curves can be employed to reproduce the effect of any pressure or rate history encountered in practice.

Most of the information is obtained by the help of the Laplace transformations, which proved to be extremely helpful for analyzing the problems encountered in fluid flow. The application of this method simplifies the more tedious mathematical analyses employed in the past. With the help of Laplace transformations some original developments were obtained (and presented) which could not have been easily foreseen by the earlier methods.


## INTRODUCTION

This paper represents a compilation of the work done over the past few years on the flow of fluid in porous media. It concerns itself primarily with the transient conditions prevailing in oil reservoirs during the time they are produced. The study is limited to conditions where the flow of fluid obeys the diffusivity equation. Multiple-phase fluid flow has not been considered.

A previous publication by Hurst[1] shows that when the pressure history of a reservoir is known, this information can be used to calculate the water influx, an essential term in the material balance equation. An example is offered in the literature by Old[2] in the study of the Jones Sand, Schuler Field, Arkansas. The present paper contains extensive tabulated data (from which work curves can be constructed), which data are derived by a more rigorous treatment of the subject matter than available in an earlier publication.[1] The application of this information will enable those concerned with the analysis of the behavior of a reservoir to obtain quantitatively correct expressions for the amount of water that has flowed into the reservoirs, thereby satisfying all the terms that appear in the material balance equation. This work is likewise applicable to the flow of fluid to a well whenever the flow conditions are such that the diffusivity equation is obeyed.

## DIFFUSITY EQUATION

The most commonly encountered flow system is radial flow toward the well bore or field. The volume of fluid which flows per unit of time through each unit area of sand is expressed by Darcy's equation as

$$v = \frac{K}{\mu}\frac{\partial P}{\partial r}$$

where K is the permeability, $\mu$ the viscosity and $\partial P/\partial r$ the pressure gradient at the radial distance r. A material balance on a concentric element AB, expresses the net fluid traversing the surfaces A and B, which must equal the fluid lost from within the element. Thus, if the density of the fluid is expressed by $\rho$, then the weight of fluid per unit time and per unit sand thickness, flowing past Surface A, the surface nearest the well bore, is given as

$$2\pi r\rho \frac{K}{\mu}\frac{\partial P}{\partial r} = \frac{2\pi K}{\mu}\left(\rho r \frac{\partial P}{\partial r}\right)$$

The weight of fluid flowing past Surface B, an infinitesimal distance $\delta r$, removed from Surface A, is expressed as

$$\frac{2\pi K}{\mu}\left[\rho r \frac{\partial P}{\partial r} + \frac{\partial\left(\rho r \frac{\partial P}{\partial r}\right)}{\partial r}\delta r\right]$$

Manuscript received at office of Petroleum Branch January 12, 1949. Paper presented at the AIME Annual Meeting in San Francisco, February 13-17, 1949.

[1] References are given at end of paper.

The difference between these two terms, namely,

$$-\frac{2\pi K}{\mu}\frac{\partial\left(\rho r\frac{\partial P}{\partial r}\right)}{\partial r}\delta r,$$

is equal to the weight of fluid lost by the element AB, or

$$-2\pi f r\frac{\partial \rho}{\partial T}\delta r$$

where f is the porosity of the formation.

This relation gives the equation of continuity for the radial system, namely,

$$\frac{K}{\mu}\frac{\partial\left(\rho r\frac{\partial P}{\partial r}\right)}{\partial r}=fr\frac{\partial \rho}{\partial T} \quad . . . . \quad (II\text{-}1)$$

From the physical characteristics of fluids, it is known that density is a function of pressure and that the density of a fluid decreases with decreasing pressure due to the fact that the fluid expands. This trend expressed in exponential form is

$$\rho=\rho_o e^{-c(P_o-P)} \quad . . . . . \quad (II\text{-}2)$$

where P is less than $P_o$, and c the compressibility of the fluid. If we substitute Eq. II-2 in Eq. II-1, the diffusivity equation can be expressed using density as a function of radius and time, or

$$\left(\frac{\partial^2\rho}{\partial r^2}+\frac{1}{r}\frac{\partial \rho}{\partial r}\right)\frac{K}{f\mu c}=\frac{\partial \rho}{\partial T} \quad . . . \quad (II\text{-}3)$$

For liquids which are only slightly compressible, Eq. II-2 simplifies to $\rho\cong\rho_o[1-c(P_o-P)]$ which further modifies Eq. II-3 to give

$$\left(\frac{\partial^2 P}{\partial r^2}+\frac{1}{r}\frac{\partial P}{\partial r}\right)\frac{K}{f\mu c}=\frac{\partial P}{\partial T}.$$

Furthermore, if the radius of the well or field, $R_b$, is referred to as a unit radius, then the relation simplifies to

$$\frac{\partial^2 P}{\partial r^2}+\frac{1}{r}\frac{\partial P}{\partial r}=\frac{\partial P}{\partial t} \quad . . . . . \quad (II\text{-}4)$$

where $t=KT/f\mu cR_b^2$ and r now expresses the distance as a multiple of $R_b$, the unit radius. The units appearing in this paper are always used in connection with Darcy's equation, so that the permeability K must be expressed in darcys, the time T in seconds, the porosity f as a fraction, the viscosity $\mu$ in centipoises, the compressibility c as volume per volume per atmosphere, and the radius $R_b$ in centimeters.

## LAPLACE TRANSFORMATION

In all publications, the treatment of the diffusivity equation has been essentially the orthodox application of the Fourier-Bessel series. This paper presents a new approach to the solution of problems encountered in the study of flowing fluids, namely, the Laplace transformation, since it was recognized that Laplace transformations offer a useful tool for solving difficult problems in less time than by the use of Fourier-Bessel series. Also, original developments have been obtained which are not easily foreseen by the orthodox methods.

If $P_{(t)}$ is a pressure at a point in the sand and a function of time, then its Laplace transformation is expressed by the infinite integral

$$\overline{P}_{(p)}=\int_o^\infty e^{-pt}\,P_{(t)}\,dt \quad . . . . . \quad (III\text{-}1)$$

where the constant p in this relationship is referred to as the operator. If we treat the diffusivity equation by the process implied by Eq. III-1, the partial differential can be transformed to a total differential equation. This is performed by multiplying each term in Eq. II-4 by $e^{-pt}$ and integrating with respect to time between zero and infinity, as follows:

$$\int_o^\infty e^{-pt}\left(\frac{\partial^2 P}{\partial r^2}+\frac{1}{r}\frac{\partial P}{\partial r}\right)dt=\int_o^\infty e^{-pt}\frac{\partial P}{\partial t}dt \quad (III\text{-}2)$$

Since P is a function of radius and time, the integration with respect to time will automatically remove the time function and leave P a function of radius only. This reduces the left side to a total differential with respect to r, namely,

$$\int_o^\infty e^{-pt}\frac{\partial^2 P}{\partial r^2}\,dt=\frac{\partial^2\int_o^\infty\{e^{-pt}P\,dt\}}{\partial r^2}=\frac{d^2\overline{P}_{(p)}}{dr^2} \quad \text{etc.}$$

and Eq. III-2 becomes

$$\frac{d^2\overline{P}_{(p)}}{dr^2}+\frac{1}{r}\frac{d\overline{P}_{(p)}}{dr}=\int_o^\infty e^{-pt}\frac{dP}{dt}\,dt$$

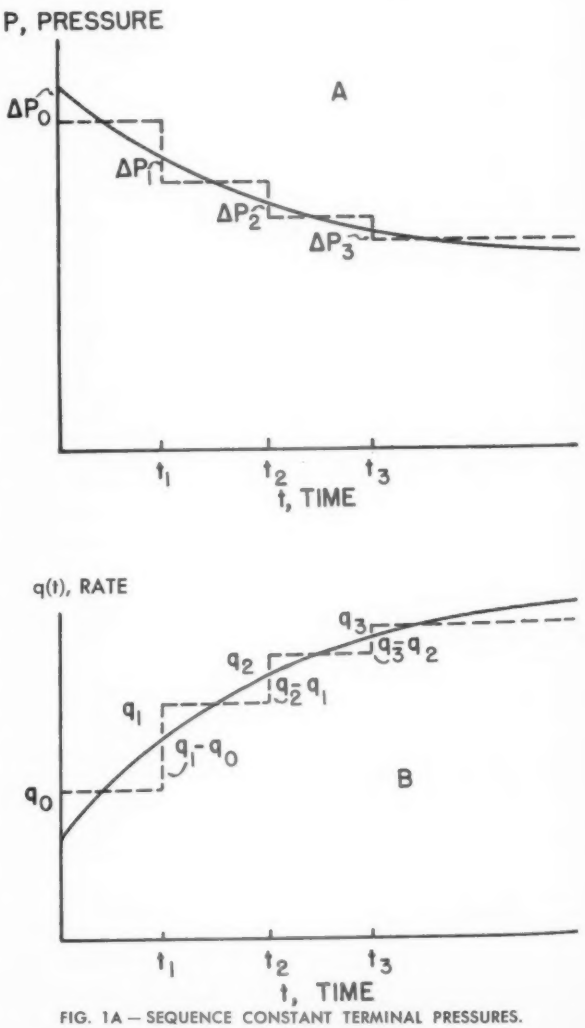



FIG. 1A — SEQUENCE CONSTANT TERMINAL PRESSURES.
1B — SEQUENCE CONSTANT TERMINAL RATES.

Furthermore, if we consider that $P_{(t)}$ is a cumulative pressure drop, and that initially the pressure in the reservoir is everywhere constant so that the cumulative pressure drop $P_{(t=0)}=0$, the integration of the right hand side of the equation becomes

$$\int_0^\infty e^{-pt}\,\frac{dP}{dt}\,dt = e^{-pt}\,P_{(t)}\,\Big|_0^\infty + p\int_0^\infty e^{-pt}\,P_{(t)}\,dt$$

$$= p\int_0^\infty e^{-pt}\,P_{(t)}\,dt$$

As this term is also a Laplace transform, Eq. III-2 can be written as a total differential equation, or

$$\frac{d^2\bar{P}_{(p)}}{dr^2} + \frac{1}{r}\,\frac{d\bar{P}_{(p)}}{dr} = p\bar{P}_{(p)} \quad . \quad . \quad . \quad . \quad \text{(III-3)}$$

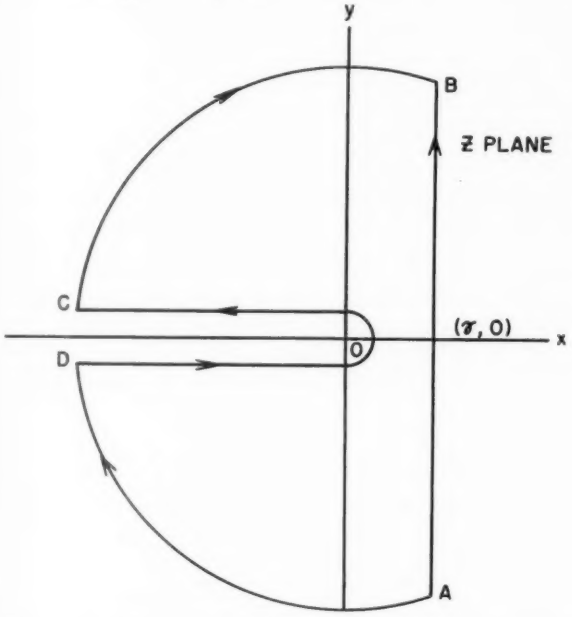



FIG. 2 — CONTOUR INTEGRATION IN ESTABLISHING THE CONSTANT TERMINAL RATE CASE FOR INFINITE EXTENT.

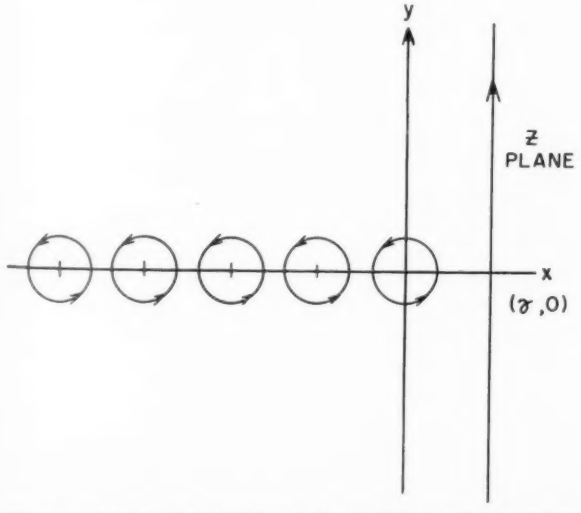



FIG. 3 — CONTOUR INTEGRATION IN ESTABLISHING THE CONSTANT TERMINAL RATE CASE FOR LIMITED RESERVOIR.

The next step in the development is to reproduce the boundary condition at the well bore or field radius, $r = 1$, as a Laplace transformation and introduce this in the general solution for Eq. III-3 to give an explicit relation

$$\bar{P}_{(p)} = f_{(p,r)}$$

By inverting the term on the right by the Mellin's inversion formula, or other methods, we obtain the solution for the cumulative pressure drop as an explicit function of radius and time.

## ENGINEERING CONCEPTS

Before applying the Laplace transformation to develop the necessary work-curves, there are some fundamental engineering concepts to be considered that will allow the interpretation of these curves. Two cases are of paramount importance in making reservoir studies, namely, the constant terminal pressure case and the constant terminal rate case. If we know the explicit solution for the first case, we can reproduce any variable pressure history at the terminal boundary to determine the cumulative influx of fluid. Likewise, if the rate of fluid influx varies, the constant terminal rate case can be used to calculate the total pressure drop. The constant terminal pressure and the constant terminal rate case are not independent of one another, as knowing the operational form of one, the other can be determined, as will be shown later.

### *Constant Terminal Pressure Case*

The constant terminal pressure case is defined as follows: At time zero the pressure at all points in the formation is constant and equal to unity, and when the well or reservoir is opened, the pressure at the well or reservoir boundary, $r = 1$, immediately drops to zero and remains zero for the duration of the production history.

If we treat the constant terminal pressure case symbolically, the solution of the problem at any radius and time is given by $P = P_{(r,t)}$. The rate of fluid influx per unit sand thickness under these conditions is given by Darcy's equation

$$q_{(T)} = \frac{2\pi K}{\mu}\left(r\,\frac{\partial P}{\partial r}\right)_{r=1} \quad . \quad . \quad . \quad . \quad \text{(IV-1)}$$

If we wish to determine the cumulative influx of fluid in absolute time T, and having expressed time in the diffusivity equation as $t = KT/f\mu cR_b^2$, then

$$Q_{(T)} = \int_0^T q_{(T)}\,dT = \frac{2\pi K}{\mu}\,x\,\frac{f\mu cR_b^2}{K}\int_0^t \left(\frac{\partial P}{\partial r}\right)_{r=1} dt$$

$$= 2\pi fcR_b^2\;Q_{(t)} \quad . \quad . \quad . \quad . \quad . \quad \text{(IV-2)}$$

where

$$Q_{(t)} = \int_0^t \left(\frac{\partial P}{\partial r}\right)_{r=1} dt \quad . \quad . \quad \text{(IV-3)}$$

In brief, knowing the general solution implied by Eq. IV-3, which expresses the integration in dimensionless time, t, of the pressure gradient at radius unity for a pressure drop of one atmosphere, the cumulative influx into the well bore or into the oil-bearing portion of the field can be determined by Eq. IV-2. Furthermore, for any pressure drop, $\Delta P$, Eq. IV-2 expresses the cumulative influx as

$$Q_{(T)} = 2\pi fcR_b^2\;\Delta P\;Q_{(t)} \quad . \quad . \quad . \quad . \quad \text{(IV-4)}$$

per unit sand thickness.*

* The set of symbols now introduced and the symbols reported in Hurst's[1] earlier paper on water-drive are related as follows:

$G(\alpha^2\,\theta/R^2) = Q_{(t)}$ and $\bar{G}(\alpha^2\,\theta/R^2) = \int_0^t Q_{(t)}\,dt$ where $\alpha^2\,\theta/R^2 = t$

When an oil reservoir and the adjoining water-bearing formations are contained between two parallel and sealing faulting planes, the flow of fluid is essentially parallel to these planes and is "linear." The constant terminal pressure case can also be applied to this case. The basic equation for linear flow is given by

$$\frac{\partial^2 P}{\partial x^2} = \frac{\partial P}{\partial t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV\text{-}5)$$

where now $t = KT/f\mu c$ and x is the absolute distance measured from the plane of influx extending out into the water-bearing sand. If we assume the same boundary conditions as in radial flow, with $P = P(x, t)$ as the solution, then by Darcy's law, the rate of fluid influx across the original water-oil contact per unit of cross-sectional area is expressed by

$$q_{(T)} = \frac{K}{\mu}\left(\frac{\partial P}{\partial x}\right)_{x=o} \quad . \quad . \quad . \quad . \quad (IV\text{-}6)$$

The total fluid influx is given by

$$Q_{(T)} = \int_o^T q_{(T)}\, dT = \frac{K}{\mu} \cdot \frac{f\mu c}{K} \int_o^t \left(\frac{\partial P}{\partial x}\right)_{x=o} dt$$
$$= f\ c\ Q_{(t)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV\text{-}7)$$

where $Q_{(t)}$ is the generalized solution for linear flow and is equal to

$$Q_{(t)} = \int_o^t \left(\frac{\partial P}{\partial x}\right)_{x=o} dt \quad . \quad (IV\text{-}8)$$

Therefore, for any over-all pressure drop $\Delta P$, Eq. IV-7 gives

$$Q_{(T)} = fc\Delta P\ Q_{(t)} \quad . \quad . \quad . \quad . \quad (IV\text{-}9)$$

per unit of cross-sectional area.

### *Constant Terminal Rate Case*

In the constant terminal rate case it is likewise assumed that initially the pressure everywhere in the formation is constant but that from the time zero onward the fluid is withdrawn from the well bore or reservoir boundary at a unit rate. The pressure drop is given by $P = P_{(r,t)}$, and at the boundary of the field, where $r = 1$, $(\partial P/\partial r)_{r=1} = -1$. The minus sign is introduced because the gradient for the pressure drop relative to the radius of the well or reservoir is negative. If the cumulative pressure drop is expressed as $\Delta P$, then

$$\Delta P = q_{(t)}\ P_{(r,t)} \quad . \quad . \quad . \quad . \quad (IV\text{-}10)$$

where $q_{(t)}$ is a constant relating the cumulative pressure drop with the pressure change for a unit rate of production. By applying Darcy's equation for the rate of fluid flowing into the well or reservoir per unit sand thickness

$$q_{(T)} = \frac{-2\pi K}{\mu}\left(\frac{\partial \Delta P}{\partial r}\right)_{r=1} = \frac{-2\pi K\ q_{(t)}}{\mu}\left(\frac{\partial P_{(r,t)}}{\partial r}\right)_{r=1}$$

which simplifies to $q_{(t)} = \dfrac{q_{(T)}\mu}{2\pi K}$. Therefore, for any constant rate of production the cumulative pressure drop at the field radius is given by

$$\Delta P = \frac{q_{(T)}\mu}{2\pi K} P_{(t)} \quad . \quad . \quad . \quad . \quad (IV\text{-}11)$$

Similarly, for the constant rate of production in linear flow, the cumulative pressure drop is expressed by

$$\Delta P = \frac{q_{(T)}\mu}{K} P_{(t)} \quad . \quad . \quad . \quad . \quad (IV\text{-}12)$$

where $q_{(T)}$ is the rate of water encroachment per unit area of cross-section, and $P_{(t)}$ is the cumulative pressure drop at the sand face per unit rate of production.

### *Superposition Theorem*

With these fundamental relationships available, it remains to be shown how the constant pressure case can be interpreted for variable terminal pressures, or in the constant rate case, for variable rates. The linearity of the diffusivity equation allows the application of the superposition theorem as a sequence of constant terminal pressures or constant rates in such a fashion that it reproduces the pressure or production history at the boundary, $r = 1$. This is essentially Duhamel's principle, for which reference can be made to transient electric circuit theory in texts by Karman and Biot,[5] and Bush.[6] It has been applied t othe flow of fluids by Muskat,[4] Schilthuis and Hurst,[7] in employing the variable rate case in calculating the pressure drop in the East Texas Field.[1]

The physical significance can best be realized by an application. Fig. 1-A shows the pressure decline in the well bore or a field that has been flowing and for which we wish to obtain the amount of fluid produced. As shown, the pressure history is reproduced as a series of pressure plateaus which represent a sequence of constant terminal pressures. Therefore, by the application of Eq. IV-4, the cumulative fluid produced in time t by the pressure drop $\Delta P_o$, operative since zero time, is expressed by $Q_{(T)} = 2\pi fcR_b^2\ \Delta P_o\ Q_{(t)}$. If we next consider

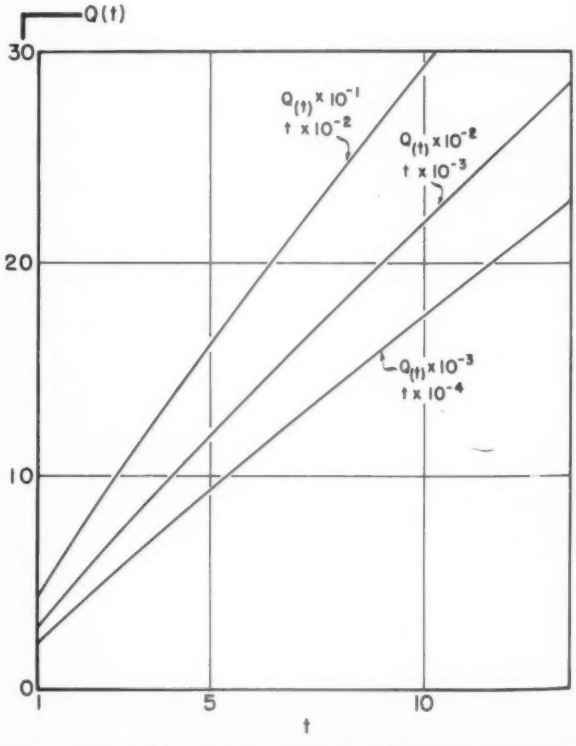



FIG. 4 — RADIAL FLOW, CONSTANT TERMINAL PRESSURE CASE, INFINITE RESERVOIR, CUMULATIVE PRODUCTION VS. TIME.

the pressure drop $\Delta P_1$, which occurs in time $t_1$, and treat this as a separate entity, but take cognizance of its time of inception $t_1$, then the cumulative fluid produced by this increment of pressure drop is $Q_{(t)} = 2\pi fcR_b^2 \ \Delta P_1 \ Q_{(t-t_1)}$. By superimposing all these effects of pressure changes, the total influx in time t is expressed as

$$Q_{(T)} = 2\pi fcR_b^2 \ [\Delta P_o Q_{(t)} + \Delta P_1 Q_{(t-t_1)} + \Delta P_2 Q_{(t-t_2)} + \Delta P_3 Q_{(t-t_3)} + \ \ldots \ ] \quad . \quad \text{(IV-13)}$$

when $t > t_3$. To reproduce the smooth curve relationship of Fig. 1-A, these pressure plateaus can be taken as infinitesimally small, which give the summation of Eq. IV-13 by the integral

$$Q_{(T)} = 2\pi fcR_b^2 \int_o^t \frac{\partial \Delta P}{\partial t'} \ Q_{(t-t')} \ dt' \quad . \quad . \quad . \quad \text{(IV-14)}$$

By considering variable rates of fluid production, such as shown in Fig. 1-B, and reproducing these rates as a series of constant rate plateaus, then by Eq. IV-11 the pressure drop in the well bore in time t, for the initial rate $q_o$ is $\Delta P_o = q_o P_{(t)}$. At time $t_1$, the comparable increment for constant rate is expressed as $q_1 - q_o$, and the effect of this increment rate on the corresponding increment of pressure drop is $\Delta P_1 = (q_1 - q_o) \ P_{(t-t_1)}$. Again by superimposing all of these effects, the determination for the cumulative pressure drop is expressed by

$$\Delta P = q_{(o)} P_{(t)} + [q_1(t_1) - q_{(o)}] P_{(t-t_1)} + [q_{(t_2)} - q_{(t_1)}] P_{(t-t_2)} + [q_{(t_3)} - q_{(t_2)}] \quad P_{(t-t_3)} + \ \text{- - -} \quad . \quad \text{(IV-15)}$$

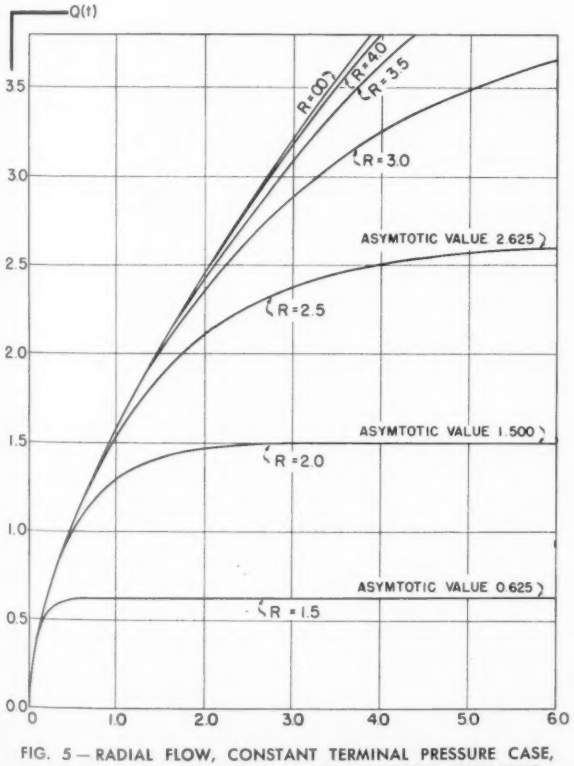



FIG. 5 — RADIAL FLOW, CONSTANT TERMINAL PRESSURE CASE, CUMULATIVE PRODUCTION VS. TIME FOR LIMITED RESERVOIRS.

If the increments are infinitesimal, or the smooth curve relationship applies, Eq. IV-15 becomes

$$\Delta P = q_{(o)} \ P_{(t)} + \int_o^t \frac{dq_{(t')}}{dt'} \ P_{(t-t')} \ dt' \quad . \quad \text{(IV-16)}$$

If $q_{(o)} = 0$, Eq. IV-16 can also be expressed as

$$\Delta P = \int_o^t q_{(t')} \ P'_{(t-t')} \ dt' \quad . \ . \ . \ . \quad \text{(IV-17)}$$

where $P'_{(t)}$ is the derivative of $P_{(t)}$ with respect to t.

Since Eqs. IV-13 and IV-15 are of such simple algebraic forms, they are most practical to use with production history in making reservoir studies. In applying the pressure or rate plateaus as shown in Fig. 1, it must be realized that the time interval for each plateau should be taken as small as possible, so as to reproduce within engineering accuracy the trend of the curves. Naturally, if an exact interpretation is desired, Eqs. IV-14 and IV-16 apply.

## FUNDAMENTAL CONSIDERATIONS

In applying the Laplace transformation, there are certain fundamental operations that must be clarified. It has been stated that if $P_{(t)}$ is a pressure drop, the transformation for $P_{(t)}$ is given by Eq. III-1, as

$$\overline{P}_{(p)} = \int_o^\infty e^{-pt} \ P_{(t)} \ dt$$

To visualize more concretely the meaning of this equation, if the unit pressure drop at the boundary in the constant terminal pressure case is employed in Eq. III-1, its transform is given by

$$\overline{P}_{(p)} = \int_o^\infty e^{-pt} \ 1 \ dt = \frac{-e^{-pt}}{p} \ 1 \Bigg|_o^\infty = \frac{1}{p} \quad . \quad \text{(V-1)}$$

The Laplace transformations of many transcendental functions have been developed and are available in tables, the most complete of which is the tract by Campbell and Foster.[8] It is therefore often possible after solving a total differential such as Eq. III-3 to refer to a set of tables and transforms and determine the inverse of $\overline{P}_{(p)}$ or $P_{(t)}$. It is frequently necessary to simplify $\overline{P}_{(p)}$ before an inversion can be made. However, Mellin's inversion formula is always applicable, which requires analytical treatment whenever used.

There are two possible simplifications for $\overline{P}_{(p)}$ when time is small or time is large. This is evident from Eq. III-3, where p can be interpreted by the operational calculus as the operator d/dt. Therefore, if we consider this symbolic relation, then if t is large, p must be small, or inversely, if t is small, p will be large. To understand this, if $\overline{P}_{(p)}$ is expressed by an involved Bessel relationship, the substitution for p as a small or large value will simplify $\overline{P}_{(p)}$ to give $P_{(t)}$ for the corresponding times.

Mellin's inversion formula is given on page 71 of Carslaw and Jaeger:[9]

$$P_{(t)} = \frac{1}{2\pi i} \int_{\gamma-i\infty}^{\gamma+i\infty} e^{\lambda t} \, \overline{P}_{(\lambda)} \, d\lambda$$

where $\overline{P}_{(\lambda)}$ is the transform $\overline{P}_{(p)}$ Where this report is concorned with pressure drops, the above can be written as

$$P_{(t_1)} - P_{(t_2)} = \frac{1}{2\pi i} \int_{\gamma-i\infty}^{\gamma+i\infty} (e^{\lambda t_1} - e^{\lambda t_2}) \, \overline{P}_{(\lambda)} \, d\lambda . \quad \text{(V-2)}$$

The integration is in the complex plane $\lambda = x + iy$, along a line parallel to the y-axis, extending from minus to positive infinity, and a distance $\gamma$ removed from the origin, so that all poles are to the left of this line, Fig. 2. The reader who has a comprehensive understanding of contour integrals will recognize that this integral is equal to the integration around a semi-circle of infinite radius extending to the left of the line $x = \gamma$, and includes integration along the "cuts," which joins the poles to the semi-circle. Since the integration along the semi-circle in the second and third quadrant is zero for radius infinity and $t>0$, this leaves the integration along the "cuts" and the poles, where the latter, as expressed in Eq. V-2, are the residuals.

Certain fundamental relationships in the Laplace transformations are found useful:[10]

*Theorem A* — If $\overline{P}_{(p)}$ is the transform of $P_{(t)}$, then

$$\int_0^\infty e^{-pt} \frac{dP_{(t)}}{dt} dt = e^{-pt} P_{(t)} \Big|_0^\infty + p \int_0^\infty e^{-pt} P_{(t)} \, dt$$

$$= p \, \overline{P}_{(p)} - P_{(t=0)}$$

or the transform of $\frac{dP_{(t)}}{dt} = p \, \overline{P}_{(p)} - P_{(t=0)}$, provided $e^{-pt} P_{(t)}$ approaches zero as time approaches infinity.

*Theorem B* — The transform of $\int_0^\infty P_{(t')} \, dt'$ is expressed by

$$\int_0^\infty e^{-pt} \int_0^t P_{(t')} \, dt' \, dt = \frac{-e^{-pt}}{p} \int_0^t P_{(t')} \, dt' \Big|_0^\infty + \frac{1}{p} \int_0^\infty e^{-pt} P_{(t)} \, dt$$

$$= \frac{\overline{P}_{(p)}}{p}$$

or the transform of the integration $P_{(t')}$ with respect to $t'$ from zero to $t$ is $\overline{P}_{(p)}/p$, if $e^{-pt} \int_0^t P_{(t')} \, dt'$ is zero for time infinity.

*Theorem C* — The transform for $e^{\pm ct} P_{(t)}$ is equal to

$$\int_0^\infty e^{-pt} \, e^{\pm ct} P_{(t)} \, dt = \int_0^\infty e^{-(p \mp c)t} P_{(t)} \, dt = \overline{P}_{(p \mp c)}$$

if $p - c$ is positive.

*Theorem D* — If $\overline{P}_1(p)$ is the transform of $P_1(t)$, and $\overline{P}_2(p)$ is the transform of $P_{2(t)}$, then the product of these two transforms is the transform of the integral

$$\int_0^t P_{1(t')} \, P_{2(t-t')} \, dt'$$

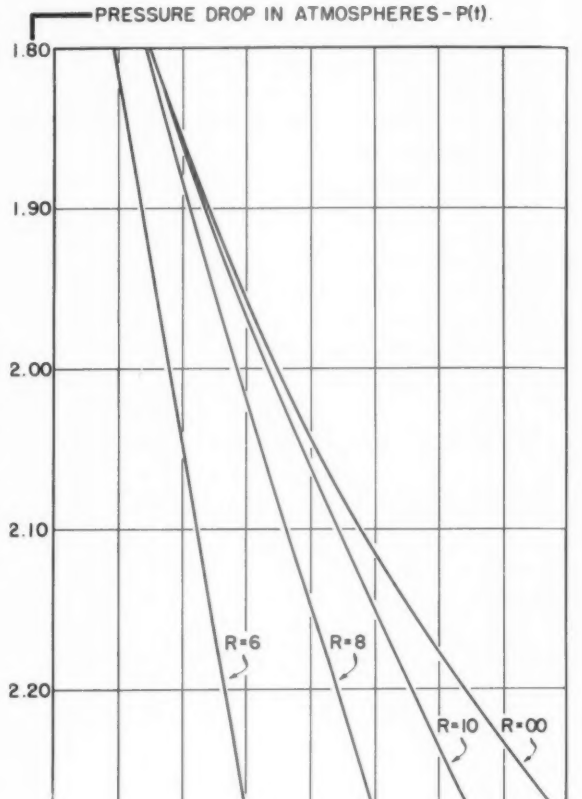



FIG. 6 — RADIAL FLOW, CONSTANT TERMINAL RATE CASE, PRESSURE DROP VS. TIME, P(t) VS. t

This integral is comparable to the integrals developed by the superimposition theorem, and of appreciable use in this paper.

## CONSTANT TERMINAL PRESSURE AND CONSTANT TERMINAL RATE CASES, INFINITE MEDIUM

The analytics for the constant terminal pressure and rate cases have been developed for limited reservoirs[3,4] when the exterior boundary is considered closed or the production rate through this boundary is fixed. In determining the volume of water encroached into the oil-bearing portion of reservoirs, few cases have been encountered which indicated that the sands in which the oil occurs are of limited extent. For the most part, the data show that the influx behaves as if the water-bearing parts of the formations are of infinite extent, because within the productive life of oil reservoirs, the rate of water encroachment does not reflect the influence of an exterior boundary. In other words, whether or not the water sand is of limited extent, the rate of water encroachment is such as if supplied by an infinite medium.

Computing the water influx for an infinite reservoir with the help of Fourier-Bessel expansions, an exterior boundary can be assumed so far removed from the field radius that the production for a considerable time will reflect the infinite case. Unfortunately, the poor convergence of these expansions invalidates this approach. An alternative method consists of using increasing values for exterior radius, evaluating the water influx for each radius separately, and then drawing the envelope of these curves, which gives the infinite case, Fig. 5. In such a procedure, each of the branch curves reflects a water reservoir of limited extent. Inasmuch as the drawing of an envelope does not give a high degree of acuracy, the solutions for the constant terminal pressure and constant terminal rate cases for an infinite medium are presented here, with values for $Q_{(t)}$ and $P_{(t)}$ calculated directly.

The constant terminal pressure case was first developed by Nicholson[11] by the application of Green's function to an instantaneous circular source in an infinite medium. Goldstein[12] presented this solution by the operational method, and Smith[13] employed Carslaw's contour method in its development. Carslaw and Jaeger[14,21] later gave the explicit treatment of the constant terminal pressure case by the application of the Laplace transformation. The derivation of the constant terminal rate case is not given in the literature, and its development is presented here.

### *The Constant Rate Case*

As already discussed, the boundary conditions for the constant rate case in an infinite medium are that (1) the pressure drop $P_{(r,t)}$ is zero initially at every point in the formation, and (2) at the radius of the field ($r = 1$) we have $\left(\frac{\partial P}{\partial r}\right)_{r=1} = -1$ at all times.

A reference to a text on Bessel functions, such as Karman and Biot,[5] pp. 61-63, shows that the general solution for Eq. III-3 is given by

$$\overline{P}_{(r,p)} = A\, I_o\,(r\sqrt{p}\,) + B\, K_o\,(r\sqrt{p}\,) \quad . \quad \text{(VI-1)}$$

where $I_o\,(r\sqrt{p}\,)$ and $K_o(r\sqrt{p}\,)$ are modified Bessel functions of the first and second kind, respectively, and of zero order. A and B are two constants which satisfy a second order differential equation. Since $\overline{P}(r,p)$ is the transform of the pressure drop at a point in the formation, and because at a point not yet affected by production the absolute pressure equals the initial pressure, it is required that $\overline{P}(r,p)$ should approach zero as r becomes large. As shown in Karman and Biot,[5] $I_o(r\sqrt{p}\,)$ becomes increasingly large and $K_o(r\sqrt{p}\,)$ approaches zero as the argument $(r\sqrt{p}\,)$ increases. Therefore, to obey the initial condition, the constant A must equal zero and (VI-1) becomes

$$\overline{P}_{(r,p)} = B\, K_o(r\sqrt{p}\,) \quad . \quad . \quad . \quad . \quad . \quad \text{(VI-2)}$$

To fulfill the second boundary condition for unit rate of production, namely $(\partial P/\partial r)_{r=1} = -1$, the transform for unity gives

$$\left(\frac{\partial \overline{P}}{\partial r}\right)_{r=1} = -\frac{1}{p} \quad . \quad . \quad . \quad . \quad \text{(VI-3)}$$

by Eq. V-1. The differentiation of the modified Bessel function of the second kind, Watson's Bessel Functions,[16] W.B.F., p. 79, gives $K_o'(z) = -K_1(z)$. Therefore, differentiation Eq.

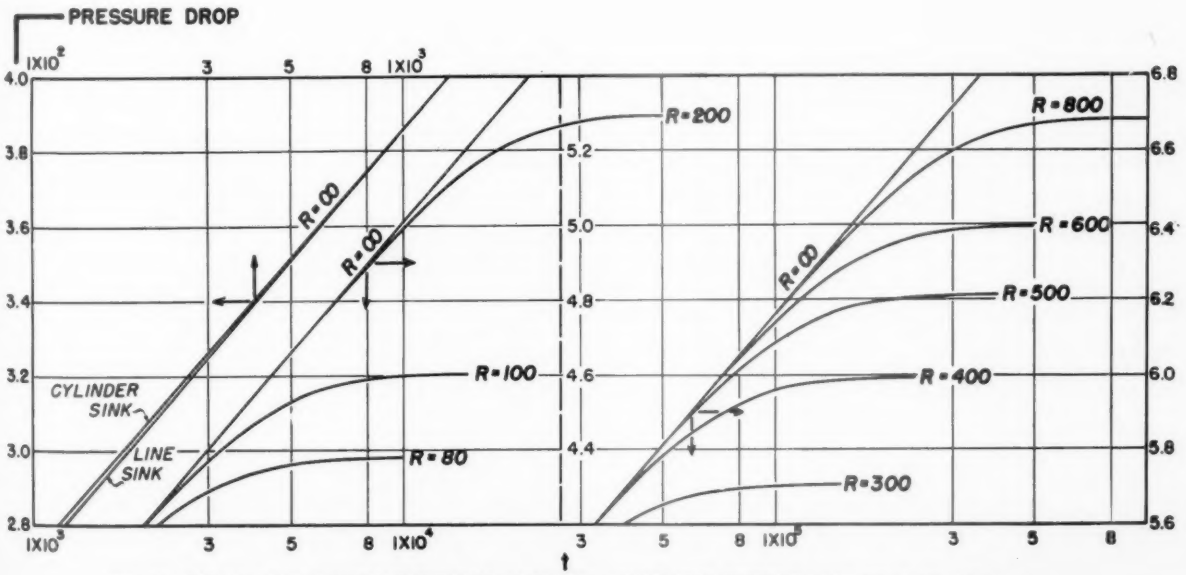



FIG. 7 — RADIAL FLOW, CONSTANT TERMINAL RATE CASE, CUMULATIVE PRESSURE DROP VS. TIME P(t) VS. t

VI-2, with respect to r at r = 1, gives

$$\left(\frac{\partial \bar{P}}{\partial r}\right)_{r=1} = -B\sqrt{p}\ K_1(\sqrt{p})$$

and since

$$\left(\frac{\partial \bar{P}}{\partial r}\right)_{r=1} = -\frac{1}{p}$$

the constant $B = 1/p^{3/2}\ K_1(\sqrt{p})$. Therefore, the transform for the pressure drop for the constant rate case in an infinite medium is given by

$$\bar{P}_{(r,p)} = \frac{K_0(r\sqrt{p})}{p^{3/2}K_1(\sqrt{p})} \quad \ldots\ldots \text{(VI-4)}$$

To determine the inverse of Eq. VI-4 in order to establish the pressure drop at radius unity, we can resort to the simplification that for small times the operator p is large. Since

$$K_n(z) = \sqrt{\frac{\pi}{2z}}\ e^{-z} \quad \ldots\ldots \text{(VI-5)}$$

for z large, W.B.F., p. 202, then

$$\bar{P}_{(1,p)} = \frac{1}{p^{3/2}} \quad \ldots\ldots \text{(VI-6)}$$

The inversion for this transform is given in Campbell and Foster, Eq. 516, as

$$P_{(t)} = \frac{2}{\sqrt{\pi}}\ t^{1/2} \quad \ldots \text{(VI-7)}$$

In brief, Eq. VI-7 states that when $t = KT/f\mu cR_b^2$ is small, which can be caused by the boundary radius for the field, $R_b$, being large, the pressure drop for the unit rate of production approximates the condition for linear flow.

To justify this conclusion, the treatment of the linear flow equation, Eq. IV-5, by the Laplace transformation gives

$$\frac{d^2\bar{P}_{(p)}}{dx^2} = p\bar{P}_{(p)} \quad \ldots\ldots \text{(VI-8)}$$

for which the general solution is the expression

$$\bar{P}_{(x,p)} = Ae^{-x\sqrt{p}} + Be^{+x\sqrt{p}} \quad \ldots \text{(VI-9)}$$

By repeating the reasoning already employed in this development, the transform for the pressure drop at x = 0 gives

$$\bar{P}(0\sqrt{p}) = 1/p^{3/2}$$

which is identical with (VI-6) with p the operator of $t = KT/f\mu c$.

The second simplification for the transform (VI-4) is to consider p small, which is equivalent to considering time, t, large. The expansions for $K_0(z)$ and $K_1(z)$ are given in Carslaw and Jaeger,[5] p. 248.

$$K_0(z) = -I_0(z)\left\{\log\frac{z}{2} + \gamma\right\} + \left(\frac{z}{2}\right)^2 + \frac{\left(1+\frac{1}{2}\right)\left(\frac{z}{2}\right)^4}{(2!)^2} + \frac{\left(1+\frac{1}{2}+\frac{1}{3}\right)\left(\frac{z}{2}\right)^6}{(3!)^2} + \quad \text{(VI-10)}$$

$$K_n(z) = -(-1)^{n+1}\ I_n(z)\ \left\{\log\frac{z}{2} + \gamma\right\} + \frac{1}{2}(-1)^n \sum_{r=0}^{\infty} \frac{\left(\frac{z}{2}\right)^{n+2r}}{r!\,(n+r)!}\left[\sum_{m=1}^{n+r} m^{-1} + \sum_{m=1}^{r} m^{-1}\right] + \frac{1}{2}\sum_{r=0}^{n-1}(-1)^r \left(\frac{z}{2}\right)^{-n+2r}\frac{(n-r-1)!}{r!} \quad \ldots \text{(VI-11)}$$

where $\gamma$ is Euler's constant 0.57722, and the logarithmic term consists of natural logarithms. When z is small

$$K_0(z) \cong -\left[\log\frac{z}{2} + \gamma\right] \quad \ldots \text{(VI-12)}$$

$$K_1(z) \cong 1/z \quad \ldots\ldots\ldots \text{(VI-13)}$$

Therefore, Eq. VI-4 becomes

$$\bar{P}_{(1,p)} = \frac{-\log p}{2p} + \frac{(\log 2 - \gamma)}{p} \quad \ldots \text{(VI-14)}$$

The inversion for the first term on the right is given by Campbell and Foster, Eq. 892, and the inverse of the second term by

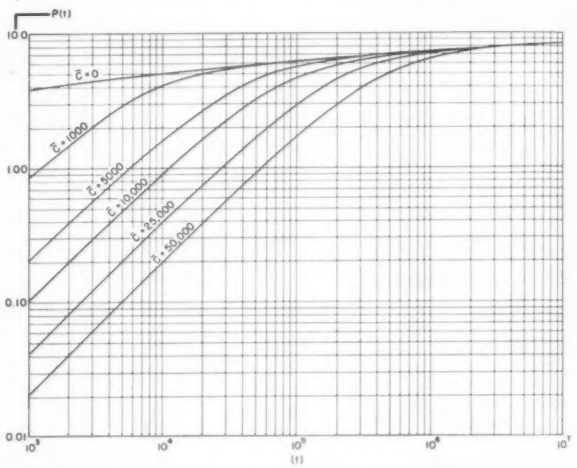



FIG. 8 — CONSTANT RATE OF PRODUCTION IN THE STOCK TANK, ADJUSTING FOR THE UNLOADING OF FLUID IN THE ANNULUS, P(t) VERSUS t where $\bar{c} = c/2\pi fcR_b^2$, AND c is the VOLUME OF FLUID UNLOADED FROM THE ANNULUS, CORRECTED TO RESERVOIR CONDITIONS, PER ATMOSPHERE BOTTOM-HOLE PRESSURE DROP, PER UNIT SAND THICKNESS.

Eq. V-1. Therefore, the pressure drop at the boundary of the field when t is large is given by

$$P_{(t)} = \frac{1}{2}\left[\log 4t - \gamma\right] = \frac{1}{2}\left[\log t + 0.80907\right] \quad \ldots \text{(VI-15)}$$

The solution given by Eq. VI-15 is the solution of the continuous point source problem for large time t. The relationship has been applied to the flow of fluids by Bruce,[19] Elkins,[20] and others, and is particularly applicable for study of interference between flowing wells.

The point source solution originally developed by Lord Kelvin and discussed in Carslaw[18] can be expressed as

$$P_{(r,t)} = \frac{1}{2}\int_{\frac{1}{4t}}^{\infty} \frac{e^{-n}}{n}\,dn = \frac{1}{2}\left\{-\mathrm{Ei}\left(-\frac{1}{4t}\right)\right\} \quad \ldots \text{(VI-16)}$$

often referred to as the logarithmic integral or the Ei-function. Its values are given in Tables of Sine, Cosine, and Exponential Integrals, Volumes I and II, Federal Works Agency, W.P.A., City of New York. For large values of the time, t, Eq. VI-16 reduces to $P_{(r,t)} = \frac{1}{2}\left[\log 4t - \gamma\right]$ which is Eq. VI-15, and this relation is accurate for values of t > 100.

By this development it is evident that the point source solution does not apply at a boundary for the determination of the pressure drop when t is small. However, when the radius, $R_b$, is small, such as a well radius, even small values of the absolute time, T will give large values of the dimensionless time t, and the point source solution is applicable. On the other hand, in considering the pressure drop at the periphery of a field (in which case $R_b$ can have a large numerical value) the value of t can be easily less than 100 even for large values of absolute time, T. Therefore, for intermediate times, the rigorous solution of the constant rate case must be used, which we will now proceed to obtain.

To develop the explicit solution for the constant terminal rate case, it is necessary to invert the Laplace transform, Eq. VI-4, by the Mellin's inversion formula. The path of integration for this transform is described by the "cut" along the negative real axis, Fig. 2, which gives a single valued function on each side of the "cut." That is to say that Path AB required by Eq. V-2 is equal to the Path AD and CB, both of which are described by a semi-circle of radius infinity. Since its integration is zero in the second and third quadrant, this leaves the integration along Paths DO and OC equal to AB. The integration on the upper portion of the "cut" can be obtained by making $\lambda = u^2 e^{i\pi}$, which yields

$$\frac{1}{2\pi i}\int_{o}^{-\infty} \frac{(e^{\lambda t_1} - e^{\lambda t_2})\, K_o(\sqrt{\lambda}\, r)}{\lambda^{3/2}\, K_1(\sqrt{\lambda})}\, d\lambda = \frac{1}{\pi i}\int_{o}^{\infty} \frac{(e^{-u^2 t_1} - e^{-u^2 t_2})\, K_o(u\, e^{\frac{i\pi}{2}}\, r)}{u^2\, e^{i\pi}\, K_1(u\, e^{\frac{i\pi}{2}})}\, du \quad \ldots \quad \text{(VI-17)}$$

Carslaw and Jaeger[9] (page 249) shows that modified Bessel functions of the first and second kind of arguments $z\, e^{\pm\frac{i\pi}{2}}$ can be expressed by the regular Bessel functions as complex values, as follows:

$$I_o(z\, e^{\pm\frac{i\pi}{2}}) = J_o(z)$$

$$K_o(z\, e^{\pm\frac{i\pi}{2}}) = \mp \frac{\pi i}{2}\{ J_o(z) \mp i\, Y_o(z) \}$$

$$I_1(z\, e^{\pm\frac{i\pi}{2}}) = \pm i\, J_1(z) \quad \ldots \quad \text{(VI-18)}$$

and

$$K_1(z\, e^{\pm\frac{i\pi}{2}}) = -\frac{\pi}{2}[\, J_1(z) \mp i\, Y_1(z)\,]$$

The substitution of the corresponding values for $K_o(u\, e^{i\pi/2}\, r)$ and $K_1(u\, e^{i\pi/2})$ from Eq. VI-18 in Eq. VI-17 gives the integration along the upper portion of the negative real "cut" as

$$\frac{1}{\pi}\int_{o}^{\infty} \frac{(e^{-u^2 t_1} - e^{-u^2 t_2})\,[Y_1(u)\, J_o(u\,r) - J_1(u)\, Y_o(u\,r)]\, du}{u^2\,[J_1^2(u) + Y_1^2(u)]} \quad \text{(VI-19)}$$

where the imaginary term has been dropped.

Likewise, the integration along the under portion of the negative real "cut" is expressed by $\lambda = u^2 e^{-i\pi}$ and

$$\frac{1}{2\pi}\int_{o}^{-\infty} \frac{(e^{\lambda t_1} - e^{\lambda t_2})\, K_o(\sqrt{\lambda}\, r)\, d\lambda}{\lambda^{3/2}\, K_1(\sqrt{\lambda})} = -\frac{1}{\pi}\int_{o}^{\infty} \frac{(e^{-u^2 t_1} - e^{-u^2 t_2})\, K_o(u\, e^{-i\pi/2}\, r)\, du}{u^2\, e^{-i\pi/2}\, K_1(u\, e^{-i\pi/2})}$$

Using Eq. VI-18, yields the relationship

$$\frac{1}{\pi}\int_{o}^{\infty} \frac{(e^{-u^2 t_1} - e^{-u^2 t_2})\,[Y_1(u)\, J_o(u\,r) - J_1(u)\, Y_o(u\,r)]\, du}{u^2\,[J_1^2(u) + Y_1^2(u)]} \quad \text{(VI-20)}$$

The integration along Paths DO and OC is the sum of the relations VI-19 and VI-20, or

$$P_{(r,\, t_1)} - P_{(r,\, t_2)} = \frac{2}{\pi}\int_{o}^{\infty} \frac{(e^{-u^2 t_1} - e^{-u^2 t_2})\,[Y_1(u)\, J_o(u\,r) - J_1(u)\, Y_o(u\,r)]\, du}{u^2[J_1^2(u) + Y_1^2(u)]}$$

Initially, that is at time zero, the cumulative pressure drop at any point in the formation is zero, $P_{(r,\, t=o)} = 0$. Hence, the pressure drop since zero time equals:

$$P_{(r,t)} = \frac{2}{\pi}\int_{o}^{\infty} \frac{(1 - e^{-u^2 t})\,[J_1(u)\, Y_o(u\,r) - Y_1(u)\, J_o(u\,r)]\, du}{u^2[J_1^2(u) + Y_1^2(u)]} \quad \text{(VI-21)}$$

which is the explicit solution of the constant terminal rate case for an infinite medium.

To determine the cumulative pressure drop for a unit rate of production at the well bore or field radius, (where $r = 1$) then Eq. VI-21 changes to

$$P_{(1,\, t)} = \frac{2}{\pi}\int_{o}^{\infty} \frac{(1 - e^{-u^2 t})\,[J_1(u)\, Y_o(u) - Y_1(u)\, J_o(u)]\, du}{u^2\,[J_1^2(u) + Y_1^2(u)]} \quad \text{(VI-22)}$$

By the recurrence formula given in W.B.F., p. 77

$$J_1(u)\, Y_o(u) - J_o(u)\, Y_1(u) = \frac{2}{\pi u} \quad \ldots \quad \text{(VI-23)}$$

Equation VI-22 simplifies to

$$P_{(1,\, t)} = \frac{4}{\pi^2}\int_{o}^{\infty} \frac{(1 - e^{-u^2 t})\, du}{u^3\,[J_1^2(u) + Y_1^2(u)]} \quad \ldots \quad \text{(VI-24)}$$

***Constant Terminal Pressure Case***

As already shown, the transform of the pressure drop in an infinite medium is $\overline{P}_{(r,p)} = B\, K_o(\sqrt{p}\, r)$. In the constant terminal pressure case it is assumed that at all times the pressure drop at $r = 1$ will be unity, which is expressed as a transform by Eq. V-1

$$\overline{P}_{(1,p)} = 1/p$$

By solving for the constant B at $r = 1$ in the above formula, we find $B = 1/p\, K_o(\sqrt{p})$, so that the transform for the pressure at any point in the reservoir is expressed by

$$\overline{P}_{(r,p)} = \frac{K_o(\sqrt{p}\, r)}{p\, K_o(\sqrt{p})} \quad \ldots \quad \text{(VI-25)}$$

The comparable solution of VI-25 for a cumulative pressure drop can be developed as before by considering the paths of Fig. 2, with a pole at the origin, to give the solution

$$P_{(r,\,t_1)} - P_{(r,\,t_2)} = \frac{2}{\pi}\int_0^\infty \frac{(e^{-u^2t_1} - e^{-u^2t_2})\,[J_o(u)\;Y_o(u\,r) - Y_o(u)\;J_o(u\,r)]\,du}{u^2[J_o^2(u) + Y_o^2(u)]} \quad . \; . \; . \; (VI\text{-}26)$$

If we are interested in the cumulative fluid influx at the field radius, r = 1, then the relationship Eq. IV-3 applies, or

$$Q_{(t)} = \int_0^t \left(\frac{\partial P}{\partial r}\right)_{r=1} dt \quad . \; . \; . \; (IV\text{-}3)$$

The determination of the transform of the gradient of the pressure drop at the field's edge follows from Eq. VI-25,

$$\left(\frac{\partial \overline{P}_{(r,\,p)}}{\partial r}\right)_{r=1} = -\frac{K_1(\sqrt{p})}{p^{1/2}\,K_o(\sqrt{p})}$$

since $K_o'(z) = -K_1(z)$. Since the pressure drop $P_{(r,\,t)}$ corresponds to the difference between the initial and actual pressure, the transform of the gradient of the actual pressure at r = 1 is given by

$$\left(\frac{\partial \overline{P}}{\partial r}\right)_{r=1} = \left(\frac{-\partial \overline{P}_{(r,p)}}{\partial r}\right)_{r=1}$$

or

$$\left(\frac{\partial \overline{P}}{\partial r}\right)_{r=1} = \frac{K_1(\sqrt{p})}{p^{1/2}\,K_o(\sqrt{p})}$$

which corresponds to the integrand of Eq. IV-3. Further, from the definition given by Theorem B, namely, that if $\overline{P}(p)$ is the transform of $P_{(t)}$, then the transform of $\int_0^t P_{(t')}\,dt'$ is given by $\overline{P}(p)/p$ and the Laplace transform for $Q_{(t)}$ is expressed by

$$\overline{Q}_{(p)} = \frac{K_1(\sqrt{p})}{p^{3/2}\,K_o(\sqrt{p})} \quad . \; . \; . \; . \; (VI\text{-}27)$$

The application of the Mellin's inversion formula to Eq. VI-27 follows the paths shown in Fig. 2, giving

$$Q_{(t)} = \frac{4}{\pi^2}\int_0^\infty \frac{(1 - e^{-u^2t})\,du}{u^3\,[J_o^2(u) + Y_o^2(u)]} \quad . \; . \; . \; (VI\text{-}28)$$

With respect to the transform $\overline{Q}_{(p)}$, there is the simplification that for time small, p is large, or Eq. VI-27 reduces to

$$\overline{Q}_{(p)} = 1/p^{3/2} \quad . \; . \; . \; . \; . \; . \; . \; (VI\text{-}29)$$

and the inversion is as before

$$Q_{(t)} = \frac{2}{\sqrt{\pi}}\,t^{1/2} \quad . \; . \; . \; . \; . \; . \; . \; (VI\text{-}30)$$

which is identical to the linear flow case. For all other values of the time, Eq. VI-28 must be solved numerically.

### *Relation Between $\overline{Q}(p)$ and $\overline{P}(p)$*

It is evident from the work that has already gone before, that the Laplace transformation and the superimposition theorem offer a basis for interchanging the constant terminal pressure to the constant terminal rate case, and vice versa. In any reservoir study the essential interest is the analyses of the flow either at the well bore or the field boundary. The purpose of this work is to determine the relationship between Q(t), the constant terminal pressure case, and P(t), the constant terminal rate case, which explicitly refer to the boundary r = 1. Therefore, if we conceive of the influx of fluid into a

TABLE I — *Radial Flow, Constant Terminal Pressure and Constant Terminal Rate Cases for Infinite Reservoirs*

| t | $Q_{(t)}$ | $P_{(t)}$ | t | $Q_{(t)}$ |
|---|---|---|---|---|
| $1.0(10)^{-2}$ | 0.112 | 0.112 | $1.5(10)^{3}$ | $4.136(10)^{2}$ |
| 5.0 " | 0.278 | 0.229 | 2.0 " | 5.315 " |
| $1.0(10)^{-1}$ | 0.404 | 0.315 | 2.5 " | 6.466 " |
| 1.5 " | 0.520 | 0.376 | 3.0 " | 7.590 " |
| 2.0 " | 0.606 | 0.424 | 4.0 " | 9.757 " |
| 2.5 " | 0.689 | 0.469 | 5.0 " | 11.88 " |
| 3.0 " | 0.758 | 0.503 | 6.0 " | 13.95 " |
| 4.0 " | 0.893 | 0.564 | 7.0 " | 15.99 " |
| 5.0 " | 1.020 | 0.616 | 8.0 " | 18.00 " |
| 6.0 " | 1.140 | 0.659 | 9.0 " | 19.99 " |
| 7.0 " | 1.251 | 0.702 | $1.0(10)^{4}$ | 21.96 " |
| 8.0 " | 1.359 | 0.735 | 1.5 " | $3.146(10)^{3}$ |
| 9.0 " | 1.469 | 0.772 | 2.0 " | 4.079 " |
| 1.0 | 1.570 | 0.802 | 2.5 " | 4.994 " |
| 1.5 | 2.032 | 0.927 | 3.0 " | 5.891 " |
| 2.0 | 2.442 | 1.020 | 4.0 " | 7.634 " |
| 2.5 | 2.838 | 1.101 | 5.0 " | 9.342 " |
| 3.0 | 3.209 | 1.169 | 6.0 " | 11.03 " |
| 4.0 | 3.897 | 1.275 | 7.0 " | 12.69 " |
| 5.0 | 4.541 | 1.362 | 8.0 " | 14.33 " |
| 6.0 | 5.148 | 1.436 | 9.0 " | 15.95 " |
| 7.0 | 5.749 | 1.500 | $1.0(10)^{5}$ | 17.56 " |
| 8.0 | 6.314 | 1.556 | 1.5 " | $2.538(10)^{4}$ |
| 9.0 | 6.861 | 1.604 | 2.0 " | 3.308 " |
| $1.0(10)^{1}$ | 7.417 | 1.651 | 2.5 " | 4.066 " |
| 1.5 " | 9.965 | 1.829 | 3.0 " | 4.817 " |
| 2.0 " | $1.229(10)^{1}$ | 1.960 | 4.0 " | 6.267 " |
| 2.5 " | 1.455 " | 2.067 | 5.0 " | 7.699 " |
| 3.0 " | 1.681 " | 2.147 | 6.0 " | 9.113 " |
| 4.0 " | 2.088 " | 2.282 | 7.0 " | 10.51 " |
| 5.0 " | 2.482 " | 2.388 | 8.0 " | 11.89 " |
| 6.0 " | 2.860 " | 2.476 | 9.0 " | 13.26 " |
| 7.0 " | 3.228 " | 2.550 | $1.0(10)^{6}$ | 14.62 " |
| 8.0 " | 3.599 " | 2.615 | 1.5 " | $2.126(10)$ |
| 9.0 " | 3.942 " | 2.672 | 2.0 " | 2.781 " |
| $1.0(10)^{2}$ | 4.301 " | 2.723 | 2.5 " | 3.427 " |
| 1.5 " | 5.980 " | 2.921 | 3.0 " | 4.064 " |
| 2.0 " | 7.586 " | 3.064 | 4.0 " | 5.313 " |
| 2.5 " | 9.120 " | 3.173 | 5.0 " | 6.544 " |
| 3.0 " | 10.58 " | 3.263 | 6.0 " | 7.761 " |
| 4.0 " | 13.48 " | 3.406 | 7.0 " | 8.965 " |
| 5.0 " | 16.24 " | 3.516 | 8.0 " | 10.16 " |
| 6.0 " | 18.97 " | 3.608 | 9.0 " | 11.34 " |
| 7.0 " | 21.60 " | 3.684 | $1.0(10)^{7}$ | 12.52 " |
| 8.0 " | 24.23 " | 3.750 | | |
| 9.0 " | 26.77 " | 3.809 | | |
| $1.0(10)^{3}$ | 29.31 " | 3.860 | | |

TABLE I — *Continued*

| t | $Q_{(t)}$ | t | $Q_{(t)}$ |
|---|---|---|---|
| $1.5(10)^{7}$ | $1.828(10)^{5}$ | $1.5(10)^{11}$ | $1.17(10)^{10}$ |
| 2.0 " | 2.398 " | 2.0 " | 1.55 " |
| 2.5 " | 2.961 " | 2.5 " | 1.92 " |
| 3.0 " | 3.517 " | 3.0 " | 2.29 " |
| 4.0 " | 4.610 " | 4.0 " | 3.02 " |
| 5.0 " | 5.689 " | 5.0 " | 3.75 " |
| 6.0 " | 6.758 " | 6.0 " | 4.47 " |
| 7.0 " | 7.816 " | 7.0 " | 5.19 " |
| 8.0 " | 8.866 " | 8.0 " | 5.89 " |
| 9.0 " | 9.911 " | 9.0 " | 6.58 " |
| $1.0(10)^{8}$ | 10.95 " | $1.0(10)^{12}$ | 7.28 " |
| 1.5 " | $1.604(10)^{7}$ | 1.5 " | $1.08(10)^{11}$ |
| 2.0 " | 2.108 " | 2.0 " | 1.42 " |
| 2.5 " | 2.607 " | | |
| 3.0 " | 3.100 " | | |
| 4.0 " | 4.071 " | | |
| 5.0 " | 5.032 " | | |
| 6.0 " | 5.984 " | | |
| 7.0 " | 6.928 " | | |
| 8.0 " | 7.865 " | | |
| 9.0 " | 8.797 " | | |
| $1.0(10)^{9}$ | 9.725 " | | |
| 1.5 " | $1.429(10)^{8}$ | | |
| 2.0 " | 1.880 " | | |
| 2.5 " | 2.328 " | | |
| 3.0 " | 2.771 " | | |
| 4.0 " | 3.645 " | | |
| 5.0 " | 4.510 " | | |
| 6.0 " | 5.368 " | | |
| 7.0 " | 6.220 " | | |
| 8.0 " | 7.066 " | | |
| 9.0 " | 7.909 " | | |
| $1.0(10)^{10}$ | 8.747 " | | |
| 1.5 " | $1.288(10)^{9}$ | | |
| 2.0 " | 1.697 " | | |
| 2.5 " | 2.103 " | | |
| 3.0 " | 2.505 " | | |
| 4.0 " | 3.299 " | | |
| 5.0 " | 4.087 " | | |
| 6.0 " | 4.868 " | | |
| 7.0 " | 5.643 " | | |
| 8.0 " | 6.414 " | | |
| 9.0 " | 7.183 " | | |
| $1.0(10)^{11}$ | 7.948 " | | |

TABLE II — *Constant Terminal Pressure Case Radial Flow, Limited Reservoirs*

| R = 1.5 $a_1$ = 2.8899 $a_2$ = 9.3452 | | R = 2.0 $a_1$ = 1.3606 $a_2$ = 4.6458 | | R = 2.5 $a_1$ = 0.8663 $a_2$ = 3.0875 | | R = 3.0 $a_1$ = 0.6256 $a_2$ = 2.3041 | |
|---|---|---|---|---|---|---|---|
| t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ |
| $5.0(10)^{-2}$ | 0.276 | $5.0(10)^{-2}$ | 0.278 | $1.0(10)^{-1}$ | 0.4087 | $3.0(10)^{-1}$ | 0.755 |
| 6.0 " | 0.304 | 7.5 " | 0.345 | 1.5 " | 0.509 | 4.0 " | 0.895 |
| 7.0 " | 0.330 | $1.0(10)^{-1}$ | 0.404 | 2.0 " | 0.599 | 5.0 " | 1.023 |
| 8.0 " | 0.354 | 1.25 " | 0.458 | 2.5 " | 0.681 | 6.0 " | 1.143 |
| 9.0 " | 0.375 | 1.50 " | 0.507 | 3.0 " | 0.758 | 7.0 " | 1.256 |
| $1.0(10)^{-1}$ | 0.395 | 1.75 " | 0.553 | 3.5 " | 0.829 | 8.0 " | 1.363 |
| 1.1 " | 0.414 | 2.00 " | 0.597 | 4.0 " | 0.897 | 9.0 " | 1.465 |
| 1.2 " | 0.431 | 2.25 " | 0.638 | 4.5 " | 0.962 | 1.00 | 1.563 |
| 1.3 " | 0.446 | 2.50 " | 0.678 | 5.0 " | 1.024 | 1.25 | 1.791 |
| 1.4 " | 0.461 | 2.75 " | 0.715 | 5.5 " | 1.083 | 1.50 | 1.997 |
| 1.5 " | 0.474 | 3.00 " | 0.751 | 6.0 " | 1.140 | 1.75 | 2.184 |
| 1.6 " | 0.486 | 3.25 " | 0.785 | 6.5 " | 1.195 | 2.00 | 2.353 |
| 1.7 " | 0.497 | 3.50 " | 0.817 | 7.0 " | 1.248 | 2.25 | 2.507 |
| 1.8 " | 0.507 | 3.75 " | 0.848 | 7.5 " | 1.229 | 2.50 | 2.646 |
| 1.9 " | 0.517 | 4.00 " | 0.877 | 8.0 " | 1.348 | 2.75 | 2.772 |
| 2.0 " | 0.525 | 4.25 " | 0.905 | 8.5 " | 1.395 | 3.00 | 2.886 |
| 2.1 " | 0.533 | 4.50 " | 0.932 | 9.0 " | 1.440 | 3.25 | 2.990 |
| 2.2 " | 0.541 | 4.75 " | 0.958 | 9.5 " | 1.484 | 3.50 | 3.084 |
| 2.3 " | 0.548 | 5.00 " | 0.983 | 1.0 | 1.526 | 3.75 | 3.170 |
| 2.4 " | 0.554 | 5.50 " | 1.028 | 1.1 | 1.605 | 4.00 | 3.247 |
| 2.5 " | 0.559 | 6.00 " | 1.070 | 1.2 | 1.679 | 4.25 | 3.317 |
| 2.6 " | 0.565 | 6.50 " | 1.108 | 1.3 | 1.747 | 4.50 | 3.381 |
| 2.8 " | 0.574 | 7.00 " | 1.143 | 1.4 | 1.811 | 4.75 | 3.439 |
| 3.0 " | 0.582 | 7.50 " | 1.174 | 1.5 | 1.870 | 5.00 | 3.491 |
| 3.2 " | 0.588 | 8.00 " | 1.203 | 1.6 | 1.924 | 5.50 | 3.581 |
| 3.4 " | 0.594 | 9.00 " | 1.253 | 1.7 | 1.975 | 6.00 | 3.656 |
| 3.6 " | 0.599 | 1.00 | 1.295 | 1.8 | 2.022 | 6.50 | 3.717 |
| 3.8 " | 0.603 | 1.1 | 1.330 | 2.0 | 2.106 | 7.00 | 3.767 |
| 4.0 " | 0.606 | 1.2 | 1.358 | 2.2 | 2.178 | 7.50 | 3.809 |
| 4.5 " | 0.613 | 1.3 | 1.382 | 2.4 | 2.241 | 8.00 | 3.843 |
| 5.0 " | 0.617 | 1.4 | 1.402 | 2.6 | 2.294 | 9.00 | 3.894 |
| 6.0 " | 0.621 | 1.6 | 1.432 | 2.8 | 2.340 | 10.00 | 3.928 |
| 7.0 " | 0.623 | 1.7 | 1.444 | 3.0 | 2.380 | 11.00 | 3.951 |
| 8.0 " | 0.624 | 1.8 | 1.453 | 3.4 | 2.444 | 12.00 | 3.967 |
| | | 2.0 | 1.468 | 3.8 | 2.491 | 14.00 | 3.985 |
| | | 2.5 | 1.487 | 4.2 | 2.525 | 16.00 | 3.993 |
| | | 3.0 | 1.495 | 4.6 | 2.551 | 18.00 | 3.997 |
| | | 4.0 | 1.499 | 5.0 | 2.570 | 20.00 | 3.999 |
| | | 5.0 | 1.500 | 6.0 | 2.599 | 22.00 | 3.999 |
| | | | | 7.0 | 2.613 | 24.00 | 4.000 |
| | | | | 8.0 | 2.619 | | |
| | | | | 9.0 | 2.622 | | |
| | | | | 10.0 | 2.624 | | |

well or field as a constant rate problem, then the actual cumulative fluid produced as a function of the cumulative pressure drop is expressed by the superposition relationship in Eq. IV-14 as

$$Q_{(T)} = 2\pi fcR_b^2 \int_0^t \frac{d\triangle P}{dt'} Q_{(t-t')}\, dt' \quad . . \quad \text{(IV-14)}$$

when $\triangle P$ is the cumulative pressure drop at the well bore affected by producing the well at constant rate which is established by

$$\triangle P = \frac{q_{(T)}\ \mu\ P_{(t)}}{2\pi K} \quad . . . . . \quad \text{(IV-11)}$$

The substitution of Eq. IV-11 in IV-14 gives

$$Q_{(T)} = \frac{q_{(T)}\ f\mu cR_b^2}{K} \int_0^t \frac{d\ P_{(t')}}{dt'} Q_{(t-t')}\, dt'$$

Since the rate is constant, $Q_{(T)} = q_{(T)} \times T$, and as $t = KT/f\mu cR_b^2$ this relation becomes

$$t = \int_0^t \frac{dP_{(t')}}{dt'} Q_{(t-t')}\, dt' \quad . . . . \quad \text{(VI-31)}$$

To express Eq. VI-31 in transformation form, the transform for t is $1/p^2$, Campbell and Foster, Eq. 408.1. The transform for $P_{(t)}$ at $r = 1$ is $\overline{P}_{(p)}$, and it follows from Theorem A that the transform of $\frac{dP_{(t)}}{dt}$ is $p\overline{P}_{(p)}$ as the cumulative pressure drop $P_{(t)}$ for constant rate is zero at time zero. Finally from Theorem D, the transform for the integration of the form Eq. VI-31 is equal to the product of the transforms for each of the two terms in the integrand, or

TABLE II — *Continued*

| R = 3.5 $a_1$ = 0.4851 $a_2$ = 1.8374 | | R = 4.0 $a_1$ = 0.3935 $a_2$ = 1.5267 | | R = 4.5 $a_1$ = 0.3296 $a_2$ = 1.3051 | | R = 5.0 $a_1$ = 0.2823 $a_2$ = 1.1392 | | R = 6.0 $a_1$ = 0.2182 $a_2$ = 0.9025 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ |
| 1.00 | 1.571 | 2.00 | 2.442 | 2.5 | 2.835 | 3.0 | 3.195 | 6.0 | 5.148 |
| 1.20 | 1.761 | 2.20 | 2.598 | 3.0 | 3.196 | 3.5 | 3.542 | 6.5 | 5.440 |
| 1.40 | 1.940 | 2.40 | 2.748 | 3.5 | 3.537 | 4.0 | 3.875 | 7.0 | 5.724 |
| 1.60 | 2.111 | 2.60 | 2.893 | 4.0 | 3.859 | 4.5 | 4.193 | 7.5 | 6.002 |
| 1.80 | 2.273 | 2.80 | 3.034 | 4.5 | 4.165 | 5.0 | 4.499 | 8.0 | 6.273 |
| 2.00 | 2.427 | 3.00 | 3.170 | 5.0 | 4.454 | 5.5 | 4.792 | 8.5 | 6.537 |
| 2.20 | 2.574 | 3.25 | 3.334 | 5.5 | 4.727 | 6.0 | 5.074 | 9.0 | 6.795 |
| 2.40 | 2.715 | 3.50 | 3.493 | 6.0 | 4.986 | 6.5 | 5.345 | 9.5 | 7.047 |
| 2.60 | 2.849 | 3.75 | 3.645 | 6.5 | 5.231 | 7.0 | 5.605 | 10.0 | 7.293 |
| 2.80 | 2.976 | 4.00 | 3.792 | 7.0 | 5.464 | 7.5 | 5.854 | 10.5 | 7.533 |
| 3.00 | 3.098 | 4.25 | 3.932 | 7.5 | 5.684 | 8.0 | 6.094 | 11 | 7.767 |
| 3.25 | 3.242 | 4.50 | 4.068 | 8.0 | 5.892 | 8.5 | 6.325 | 12 | 8.220 |
| 3.50 | 3.379 | 4.75 | 4.198 | 8.5 | 6.089 | 9.0 | 6.547 | 13 | 8.651 |
| 3.75 | 3.507 | 5.00 | 4.323 | 9.0 | 6.276 | 9.5 | 6.760 | 14 | 9.063 |
| 4.00 | 3.628 | 5.50 | 4.560 | 9.5 | 6.453 | 10 | 6.965 | 15 | 9.456 |
| 4.25 | 3.742 | 6.00 | 4.779 | 10 | 6.621 | 11 | 7.350 | 16 | 9.829 |
| 4.50 | 3.850 | 6.50 | 4.982 | 11 | 6.930 | 12 | 7.706 | 17 | 10.19 |
| 4.75 | 3.951 | 7.00 | 5.169 | 12 | 7.208 | 13 | 8.035 | 18 | 10.53 |
| 5.00 | 4.047 | 7.50 | 5.343 | 13 | 7.457 | 14 | 8.339 | 19 | 10.85 |
| 5.50 | 4.222 | 8.00 | 5.504 | 14 | 7.680 | 15 | 8.620 | 20 | 11.16 |
| 6.00 | 4.378 | 8.50 | 5.653 | 15 | 7.880 | 16 | 8.879 | 22 | 11.74 |
| 6.50 | 4.516 | 9.00 | 5.790 | 16 | 8.060 | 18 | 9.338 | 24 | 12.26 |
| 7.00 | 4.639 | 9.50 | 5.917 | 18 | 8.365 | 20 | 9.731 | 25 | 12.50 |
| 7.50 | 4.749 | 10 | 6.035 | 20 | 8.611 | 22 | 10.07 | 31 | 13.74 |
| 8.00 | 4.846 | 11 | 6.246 | 22 | 8.809 | 24 | 10.35 | 35 | 14.40 |
| 8.50 | 4.932 | 12 | 6.425 | 24 | 8.968 | 26 | 10.59 | 39 | 14.93 |
| 9.00 | 5.009 | 13 | 6.580 | 26 | 9.097 | 28 | 10.80 | 51 | 16.05 |
| 9.50 | 5.078 | 14 | 6.712 | 28 | 9.200 | 30 | 10.98 | 60 | 16.56 |
| 10.00 | 5.138 | 15 | 6.825 | 30 | 9.283 | 34 | 11.26 | 70 | 16.91 |
| 11 | 5.241 | 16 | 6.922 | 34 | 9.404 | 38 | 11.46 | 80 | 17.14 |
| 12 | 5.321 | 17 | 7.004 | 38 | 9.481 | 42 | 11.61 | 90 | 17.27 |
| 13 | 5.385 | 18 | 7.076 | 42 | 9.532 | 46 | 11.71 | 100 | 17.36 |
| 14 | 5.435 | 20 | 7.189 | 46 | 9.565 | 50 | 11.79 | 110 | 17.41 |
| 15 | 5.476 | 22 | 7.272 | 50 | 9.586 | 60 | 11.91 | 120 | 17.45 |
| 16 | 5.506 | 24 | 7.332 | 60 | 9.612 | 70 | 11.96 | 130 | 17.46 |
| 17 | 5.531 | 26 | 7.377 | 70 | 9.621 | 80 | 11.98 | 140 | 17.48 |
| 18 | 5.551 | 30 | 7.434 | 80 | 9.623 | 90 | 11.99 | 150 | 17.49 |
| 20 | 5.579 | 34 | 7.464 | 90 | 9.624 | 100 | 12.00 | 160 | 17.49 |
| 25 | 5.611 | 38 | 7.481 | 100 | 9.625 | 120 | 12.0 | 180 | 17.50 |
| 30 | 5.621 | 42 | 7.490 | | | | | 200 | 17.50 |
| 35 | 5.624 | 46 | 7.494 | | | | | 220 | 17.50 |
| 40 | 5.625 | 50 | 7.497 | | | | | | |

TABLE II — *Continued*

| R = 7.0 $a_1$ = 0.1767 $a_2$ = 0.7534 | | R = 8.0 $a_1$ = 0.1476 $a_2$ = 0.6438 | | R = 9.0 $a_1$ = 0.1264 $a_2$ = 0.5740 | | R = 10.0 $a_1$ = 0.1104 $a_2$ = 0.4979 | |
|---|---|---|---|---|---|---|---|
| t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ | t | $Q_{(t)}$ |
| 9.00 | 6.851 | 9 | 6.861 | 10 | 7.417 | 15 | 9.965 |
| 9.50 | 7.127 | 10 | 7.398 | 15 | 9.945 | 20 | 12.32 |
| 10 | 7.389 | 11 | 7.920 | 20 | 12.26 | 22 | 13.22 |
| 11 | 7.902 | 12 | 8.431 | 22 | 13.13 | 24 | 14.09 |
| 12 | 8.397 | 13 | 8.930 | 24 | 13.98 | 26 | 14.95 |
| 13 | 8.876 | 14 | 9.418 | 26 | 14.79 | 28 | 15.78 |
| 14 | 9.341 | 15 | 9.895 | 28 | 15.59 | 30 | 16.59 |
| 15 | 9.791 | 16 | 10.361 | 30 | 16.35 | 32 | 17.38 |
| 16 | 10.23 | 17 | 10.82 | 32 | 17.10 | 34 | 18.16 |
| 17 | 10.65 | 18 | 11.26 | 34 | 17.82 | 36 | 18.91 |
| 18 | 11.05 | 19 | 11.70 | 36 | 18.52 | 38 | 19.65 |
| 19 | 11.46 | 20 | 12.13 | 38 | 19.19 | 40 | 20.37 |
| 20 | 11.85 | 22 | 12.95 | 40 | 19.85 | 42 | 21.07 |
| 22 | 12.58 | 24 | 13.74 | 42 | 20.48 | 44 | 21.76 |
| 24 | 13.27 | 26 | 14.50 | 44 | 21.09 | 46 | 22.42 |
| 26 | 13.92 | 28 | 15.23 | 46 | 21.69 | 48 | 23.07 |
| 28 | 14.53 | 30 | 15.92 | 48 | 22.26 | 50 | 23.71 |
| 30 | 15.11 | 34 | 17.22 | 50 | 22.82 | 52 | 24.33 |
| 35 | 16.39 | 38 | 18.41 | 52 | 23.36 | 54 | 24.94 |
| 40 | 17.49 | 40 | 18.97 | 54 | 23.89 | 56 | 25.53 |
| 45 | 18.43 | 45 | 20.26 | 56 | 24.39 | 58 | 26.11 |
| 50 | 19.24 | 50 | 21.42 | 58 | 24.88 | 60 | 26.67 |
| 60 | 20.51 | 55 | 22.46 | 60 | 25.36 | 65 | 28.02 |
| 70 | 21.45 | 60 | 23.40 | 65 | 26.48 | 70 | 29.29 |
| 80 | 22.13 | 70 | 24.98 | 70 | 27.52 | 75 | 30.49 |
| 90 | 22.63 | 80 | 26.26 | 75 | 28.48 | 80 | 31.61 |
| 100 | 23.00 | 90 | 27.28 | 80 | 29.36 | 85 | 32.67 |
| 120 | 23.47 | 100 | 28.11 | 85 | 30.18 | 90 | 33.66 |
| 140 | 23.71 | 120 | 29.31 | 90 | 30.93 | 95 | 34.60 |
| 160 | 23.85 | 140 | 30.08 | 95 | 31.63 | 100 | 35.48 |
| 180 | 23.92 | 160 | 30.58 | 100 | 32.27 | 120 | 38.51 |
| 200 | 23.96 | 180 | 30.91 | 120 | 34.39 | 140 | 40.89 |
| 500 | 24.00 | 200 | 31.12 | 140 | 35.92 | 160 | 42.75 |
| | | 240 | 31.34 | 160 | 37.04 | 180 | 44.21 |
| | | 280 | 31.43 | 180 | 37.85 | 200 | 45.36 |
| | | 320 | 31.47 | 200 | 38.44 | 240 | 46.95 |
| | | 360 | 31.49 | 240 | 39.17 | 280 | 47.94 |
| | | 400 | 31.50 | 280 | 39.56 | 320 | 48.54 |
| | | 500 | 31.50 | 320 | 39.77 | 360 | 48.91 |
| | | | | 360 | 39.88 | 400 | 49.14 |
| | | | | 400 | 39.94 | 440 | 49.28 |
| | | | | 440 | 39.97 | 480 | 49.36 |
| | | | | 489 | 39.98 | | |

$$\frac{1}{p^2} = p\bar{P}_{(p)}\,\bar{Q}_{(p)} \qquad \text{(VI-32)}$$

Evidence of this identity can be confirmed by substituting Eqs. VI-4 and VI-27 in Eq. VI-32. In brief, Eq. VI-32 is the relationship between constant terminal pressure and constant terminal rate cases. If the Laplace transformation for one is known, the transform for the other is established. This interchange can only take place in the transformations and the final solution must be by inversion.

### *Computation of* $P_{(t)}$ *and* $Q_{(t)}$

To plot $P_{(t)}$ and $Q_{(t)}$ as work-curves, it is necessary to determine numerically the value for the integrals shown in Eqs. VI-24 and VI-28. In treating the infinite integrals for $P_{(t)}$ and $Q_{(t)}$, the only difficult part is in establishing the integrals for small values of u. For larger values of u the integrands converge fairly rapidly, and Simpson's rule for numerical integration has proved sufficiently accurate.

To determine the integration for $Q_{(t)}$ in the region of the origin, Eq. VI-28 can be expressed as

$$Q_{\delta(t)} = \frac{4}{\pi^2}\int_0^{\delta} \frac{(1-e^{-u^2t})\,du}{u^3[J_o^2(u)+Y_o^2(u)]} \qquad \text{(VI-33)}$$

where the value for $\delta$ is taken such that $1-e^{-u^2t} \cong u^2t$, which is true for $u^2t$ equal to or less than 0.02, or $\delta = \sqrt{0.02/t}$ and the simplification for Eq. VI-33 becomes

$$Q_{\delta(t)} = \frac{4t}{\pi^2}\int_0^{\delta} \frac{du}{u[J_o^2(u)+Y_o^2(u)]}$$

For u less than 0.02, $J_o(u) = 1$, and

$$Y_o(u) \cong \frac{2}{\pi}\left\{\log\frac{u}{2}+\gamma\right\} = \frac{2}{\pi}\left\{\log u - 0.11593\right\}$$

As the logarithmic term is most predominant in the denominator for small values of u, this equation simplifies to

$$Q_{\delta(t)} = t\int_0^{\delta} \frac{du}{u[\log u - 0.11593]^2} = \frac{t}{[0.11593-\log\delta]} \qquad \text{(VI-34)}$$

The integration for $P_{(t)}$ close to the origin is expressed by

$$P_{\delta(t)} = \frac{4}{\pi^2}\int_0^{\delta=0.02} \frac{(1-e^{-u^2t})\,du}{u^3[J_1^2(u)+Y_1^2(u)]} \qquad \text{(VI-35)}$$

For u equal to or less than 0.02, $J_1(u) = 0$, and $Y_1(u) = 2/\pi u$ so that Eq. VI-35 reduces to

$$P_{\delta(t)} = \int_0^{\delta} \frac{(1-e^{-u^2t})}{u}\,du \qquad \text{(VI-36)}$$

If we let $n = u^2t$

$$P_{\delta(t)} = \frac{1}{2}\int_0^{\delta^2t} \frac{(1-e^{-n})}{n}\,dn \qquad \text{(VI-37)}$$

Further,

$$\int_0^{\delta^2t} \frac{(1-e^{-n})\,dn}{n} = \int_0^{1} \frac{(1-e^{-n})\,dn}{n} - \int_{\delta^2t}^{1} \frac{(1-e^{-n})\,dn}{n} \qquad \text{(VI-38)}$$

Since Euler's constant $\gamma$ is equal to

$$\gamma = \int^{1} \frac{(1-e^{-n})\,dn}{n} - \int_0^{\infty} \frac{e^{-n}}{n}\,dn$$

Substitution of this relation in Eq. VI-38 gives

$$\int_0^{\delta^2t} \frac{(1-e^{-n})\,dn}{n} = \gamma + \int_{\delta^2t}^{\infty} \frac{e^{-n}}{n}\,dn - \int_{\delta^2t}^{1} \frac{dn}{n}$$

and since the second term on the right is the Ei-function already discussed in the earlier part of this work, Eq. VI-37 reduces to

$$P_{\delta(t)} = \frac{1}{2}\left[\gamma - Ei(-\delta^2t) + \log\delta^2t\right] \qquad \text{(VI-39)}$$

TABLE III — *Constant Terminal Rate Case Radial Flow — Limited Reservoirs*

| $R_1 = 1.5$<br>$\beta_1 = 6.3225$<br>$\beta_2 = 11.924$ | | $R = 2.0$<br>$\beta_1 = 3.1965$<br>$\beta_2 = 6.3118$ | | $R = 2.5$<br>$\beta_1 = 2.1564$<br>$\beta_2 = 4.2230$ | | $R = 3.0$<br>$\beta_1 = 1.6358$<br>$\beta_2 = 3.1787$ | | $R = 3.5$<br>$\beta_1 = 1.3218$<br>$\beta_2 = 2.5526$ | | $R = 4$<br>$\beta_1 = 1.1120$<br>$\beta_2 = 2.1342$ | | $R = 4.5$<br>$\beta_1 = 0.9609$<br>$\beta_2 = 1.8356$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| $6.0(10)^{-3}$ | 0.251 | $2.2(10)^{-1}$ | 0.443 | $4.0(10)^{-1}$ | 0.565 | $5.2(10)^{-1}$ | 0.627 | 1.0 | 0.802 | 1.5 | 0.927 | 2.0 | 1.023 |
| $8.0$ " | 0.288 | 2.4 " | 0.459 | 4.2 " | 0.576 | 5.4 " | 0.636 | 1.1 | 0.830 | 1.6 | 0.948 | 2.1 | 1.040 |
| $1.0(10)^{-1}$ | 0.322 | 2.6 " | 0.476 | 4.4 " | 0.587 | 5.6 " | 0.645 | 1.2 | 0.857 | 1.7 | 0.968 | 2.2 | 1.056 |
| 1.2 " | 0.355 | 2.8 " | 0.492 | 4.6 " | 0.598 | 6.0 " | 0.662 | 1.3 | 0.882 | 1.8 | 0.988 | 2.3 | 1.072 |
| 1.4 " | 0.387 | 3.0 " | 0.507 | 4.8 " | 0.608 | 6.5 " | 0.683 | 1.4 | 0.906 | 1.9 | 1.007 | 2.4 | 1.087 |
| 1.6 " | 0.420 | 3.2 " | 0.522 | 5.0 " | 0.618 | 7.0 " | 0.703 | 1.5 | 0.929 | 2.0 | 1.025 | 2.5 | 1.102 |
| 1.8 " | 0.452 | 3.4 " | 0.536 | 5.2 " | 0.628 | 7.5 " | 0.721 | 1.6 | 0.951 | 2.2 | 1.059 | 2.6 | 1.116 |
| 2.0 " | 0.484 | 3.6 " | 0.551 | 5.4 " | 0.638 | 8.0 " | 0.740 | 1.7 | 0.973 | 2.4 | 1.092 | 2.7 | 1.130 |
| 2.2 " | 0.516 | 3.8 " | 0.565 | 5.6 " | 0.647 | 8.5 " | 0.758 | 1.8 | 0.994 | 2.6 | 1.123 | 2.8 | 1.144 |
| 2.4 " | 0.548 | 4.0 " | 0.579 | 5.8 " | 0.657 | 9.0 " | 0.776 | 1.9 | 1.014 | 2.8 | 1.154 | 2.9 | 1.158 |
| 2.6 " | 0.580 | 4.2 " | 0.593 | 6.0 " | 0.666 | 9.5 " | 0.791 | 2.0 | 1.034 | 3.0 | 1.184 | 3.0 | 1.171 |
| 2.8 " | 0.612 | 4.4 " | 0.607 | 6.5 " | 0.688 | 1.0 | 0.806 | 2.25 | 1.083 | 3.5 | 1.255 | 3.2 | 1.197 |
| 3.0 " | 0.644 | 4.6 " | 0.621 | 7.0 " | 0.710 | 1.2 | 0.865 | 2.50 | 1.130 | 4.0 | 1.324 | 3.4 | 1.222 |
| 3.5 " | 0.724 | 4.8 " | 0.634 | 7.5 " | 0.731 | 1.4 | 0.920 | 2.75 | 1.176 | 4.5 | 1.392 | 3.6 | 1.246 |
| 4.0 " | 0.804 | 5.0 " | 0.648 | 8.0 " | 0.752 | 1.6 | 0.973 | 3.0 | 1.221 | 5.0 | 1.460 | 3.8 | 1.269 |
| 4.5 " | 0.884 | 6.0 " | 0.715 | 8.5 " | 0.772 | 2.0 | 1.076 | 4.0 | 1.401 | 5.5 | 1.527 | 4.0 | 1.292 |
| 5.0 " | 0.964 | 7.0 " | 0.782 | 9.0 " | 0.792 | 3.0 | 1.328 | 5.0 | 1.579 | 6.0 | 1.594 | 4.5 | 1.349 |
| 5.5 " | 1.044 | 8.0 " | 0.849 | 9.5 " | 0.812 | 4.0 | 1.578 | 6.0 | 1.757 | 6.5 | 1.660 | 5.0 | 1.403 |
| 6.0 " | 1.124 | 9.0 " | 0.915 | 1.0 | 0.832 | 5.0 | 1.828 | | | 7.0 | 1.727 | 5.5 | 1.457 |
| | | 1.0 | 0.982 | 2.0 | 1.215 | | | | | 8.0 | 1.861 | 6.0 | 1.510 |
| | | 2.0 | 1.649 | 3.0 | 1.596 | | | | | 9.0 | 1.994 | 7.0 | 1.615 |
| | | 3.0 | 2.316 | 4.0 | 1.977 | | | | | 10.0 | 2.127 | 8.0 | 1.719 |
| | | 5.0 | 3.649 | 5.0 | 2.358 | | | | | | | 9.0 | 1.823 |
| | | | | | | | | | | | | 10.0 | 1.927 |
| | | | | | | | | | | | | 11.0 | 2.031 |
| | | | | | | | | | | | | 12.0 | 2.135 |
| | | | | | | | | | | | | 13.0 | 2.239 |
| | | | | | | | | | | | | 14.0 | 2.343 |
| | | | | | | | | | | | | 15.0 | 2.447 |

The values for the integrands for Eqs. VI-24 and VI-28 have been calculated from Bessel Tables for or greater than 0.02 as given in W.B.F., pp. 666-697. The calculations have been somewhat simplified by using the square of the modulus of

$|H_o^{(1)}(u)| = |J_o(u) + i\,Y_o(u)|$ and $|H_1^{(1)}(u)| = |J_1(u) + i\,Y_1(u)|$

which are the Bessel functions of the third kind or the Hankel functions.

Table I shows the calculated values for $Q_{(t)}$ and $P_{(t)}$ to three significant figures, starting at $t = 0.01$, the point where linear flow and radial flow start deviating. $P_{(t)}$ is calculated only to $t = 1{,}000$ since beyond this range the point source solution of Eq. VI-15 applies. The values for $Q_{(t)}$ are given up to $t = 10^{12}$.

The reader may reproduce these data as he sees fit; Fig. 4 is an illustrative plot for $Q_{(t)}$, and Fig. 7 is a semi-logarithmic relationship for $P_{(t)}$.

## LIMITED RESERVOIRS

As already mentioned, the solutions for limited reservoirs of radial symmetry have been developed by the Fourier-Bessel type of expansion.[3,4,21] Their introduction here is not only to show how the solutions may be arrived at by the Laplace transformation, but also to furnish data for $P_{(t)}$ and $Q_{(t)}$ curves when such cases are encountered in practice.

### *No Fluid Flow Across Exterior Boundary*

The first example considered is the constant terminal pressure case for radial flow of limited extent. The boundary conditions are such that at the well bore or field's edge, $r = 1$, the cumulative pressure drop is unity, and at some distance removed from this boundary at a point in the reservoir $r = R$, there exists a restriction such that no fluid can flow past this barrier so that at that point $\left(\frac{\partial P}{\partial r}\right)_{r=R} = 0$.

The general solution of Eq. VI-1 still applies, but to fulfill the boundary conditions it is necessary to re-determine values for constants A and B. The transformation of the boundary condition at $r = 1$ is expressed as

$$\frac{1}{p} = AI_o(\sqrt{p}) + BK_o(\sqrt{p}) \quad . . \quad \text{(VII-1)}$$

and at $r = R$ the condition is

$$0 = AI_1(\sqrt{p}R) - BK_1(\sqrt{p}R) \quad . . . . \quad \text{(VII-2)}$$

since it is shown in W.B.F., p. 79, that $K_o'(z) = -K_1(z)$, and $I_o'(z) = I_1(z)$. The solutions for A and B from these two simultaneous algebraic expressions are

$$A = K_1(\sqrt{p}R)/p[K_1(\sqrt{p}R)\,I_o(\sqrt{p}) + K_o(\sqrt{p})\,I_1(\sqrt{p}R)]$$

and

$$B = I_1(\sqrt{p}R)/p[K_1(\sqrt{p}R)\,I_o(\sqrt{p}) + K_o(\sqrt{p})\,I_1(\sqrt{p}R)]$$

By substituting these constants in Eq. VI-1, the general solution for the transform of the pressure drop is expressed by

$$\bar{P}_{(r,p)} = \frac{[K_1(\sqrt{p}R)\,I_o(\sqrt{p}r) + I_1(\sqrt{p}R)\,K_o(\sqrt{p}r)]}{p[K_1(\sqrt{p}R)\,I_o(\sqrt{p}) + I_1(\sqrt{p}R)\,K_o(\sqrt{p})]} \quad \text{(VII-3)}$$

To find $Q(t)$ the cumulative fluid produced for unit pressure drop, then the transform for the pressure gradient at $r = 1$ is obtained as follows:

$$-\left(\frac{\partial \bar{P}}{\partial r}\right)_{r=1} = \frac{[I_1(\sqrt{p}R)\,K_1(\sqrt{p}) - K_1(\sqrt{p}R)\,I_1(\sqrt{p})]}{p^{1/2}[K_1(\sqrt{p}R)\,I_o(\sqrt{p}) + I_1(\sqrt{p}R)\,K_o(\sqrt{p})]}$$

where the negative sign is introduced in order to make $Q(t)$

TABLE III — *Continued*

| R = 5<br>$\beta_1$ = 0.8472<br>$\beta_2$ = 1.6112 | | R = 6.0<br>$\beta_1$ = 0.6864<br>$\beta_2$ = 1.2963 | | R = 7.0<br>$\beta_1$ = 0.5782<br>$\beta_2$ = 1.0860 | | R = 8.0<br>$\beta_1$ = 0.4999<br>$\beta_2$ = 0.9352 | | R = 9.0<br>$\beta_1$ = 0.4406<br>$\beta_2$ = 0.8216 | | R = 10<br>$\beta_1$ = 0.3940<br>$\beta_2$ = 0.7333 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | | |
| 3.0 | 1.167 | 4.0 | 1.275 | 6.0 | 1.436 | 8.0 | 1.556 | 10.0 | 1.651 | 12.0 | 1.732 | | |
| 3.1 | 1.180 | 4.5 | 1.322 | 6.5 | 1.470 | 8.5 | 1.582 | 10.5 | 1.673 | 12.5 | 1.750 | | |
| 3.2 | 1.192 | 5.0 | 1.364 | 7.0 | 1.501 | 9.0 | 1.607 | 11.0 | 1.693 | 13.0 | 1.768 | | |
| 3.3 | 1.204 | 5.5 | 1.404 | 7.5 | 1.531 | 9.5 | 1.631 | 11.5 | 1.713 | 13.5 | 1.784 | | |
| 3.4 | 1.215 | 6.0 | 1.441 | 8.0 | 1.559 | 10.0 | 1.653 | 12.0 | 1.732 | 14.0 | 1.801 | | |
| 3.5 | 1.227 | 6.5 | 1.477 | 8.5 | 1.586 | 10.5 | 1.675 | 12.5 | 1.750 | 14.5 | 1.817 | | |
| 3.6 | 1.238 | 7.0 | 1.511 | 9.0 | 1.613 | 11.0 | 1.697 | 13.0 | 1.768 | 15.0 | 1.832 | | |
| 3.7 | 1.249 | 7.5 | 1.544 | 9.5 | 1.638 | 11.5 | 1.717 | 13.5 | 1.786 | 15.5 | 1.847 | | |
| 3.8 | 1.259 | 8.0 | 1.576 | 10.0 | 1.663 | 12.0 | 1.737 | 14.0 | 1.803 | 16.0 | 1.862 | | |
| 3.9 | 1.270 | 8.5 | 1.607 | 11.0 | 1.711 | 12.5 | 1.757 | 14.5 | 1.819 | 17.0 | 1.890 | | |
| 4.0 | 1.281 | 9.0 | 1.638 | 12.0 | 1.757 | 13.0 | 1.776 | 15.0 | 1.835 | 18.0 | 1.917 | | |
| 4.2 | 1.301 | 9.5 | 1.668 | 13.0 | 1.801 | 13.5 | 1.795 | 15.5 | 1.851 | 19.0 | 1.943 | | |
| 4.4 | 1.321 | 10.0 | 1.698 | 14.0 | 1.845 | 14.0 | 1.813 | 16.0 | 1.867 | 20.0 | 1.968 | | |
| 4.6 | 1.340 | 11.0 | 1.757 | 15.0 | 1.888 | 14.5 | 1.831 | 17.0 | 1.897 | 22.0 | 2.017 | | |
| 4.8 | 1.360 | 12.0 | 1.815 | 16.0 | 1.931 | 15.0 | 1.849 | 18.0 | 1.926 | 24.0 | 2.063 | | |
| 5.0 | 1.378 | 13.0 | 1.873 | 17.0 | 1.974 | 17.0 | 1.919 | 19.0 | 1.955 | 26.0 | 2.108 | | |
| 5.5 | 1.424 | 14.0 | 1.931 | 18.0 | 2.016 | 19.0 | 1.986 | 20.0 | 1.983 | 28.0 | 2.151 | | |
| 6.0 | 1.469 | 15.0 | 1.988 | 19. | 2.058 | 21.0 | 2.051 | 22.0 | 2.037 | 30.0 | 2.194 | | |
| 6.5 | 1.513 | 16.0 | 2.045 | 20.0 | 2.100 | 23.0 | 2.116 | 24.0 | 2.090 | 32.0 | 2.236 | | |
| 7.0 | 1.556 | 17.0 | 2.103 | 22. 0 | 2.184 | 25.0 | 2.180 | 26.0 | 2.142 | 34.0 | 2.278 | | |
| 7.5 | 1.598 | 18.0 | 2.160 | 24.00 | 2.267 | 30.0 | 2.340 | 28.0 | 2.193 | 36.0 | 2.319 | | |
| 8.0 | 1.641 | 19.0 | 2.217 | 26.0 | 2.351 | 35.0 | 2.499 | 30.0 | 2 244 | 38.0 | 2.360 | | |
| 9.0 | 1.725 | 20.0 | 2.274 | 28.0 | 2.434 | 40.0 | 2.658 | 34.0 | 2.345 | 40.0 | 2.401 | | |
| 10.0 | 1.808 | 25.0 | 2.560 | 30.0 | 2.517 | 45.0 | 2.817 | 38.0 | 2.446 | 50.0 | 2.604 | | |
| 11.0 | 1.892 | 30.0 | 2.846 | | | | | 40.0 | 2.496 | 60.0 | 2.806 | | |
| 12.0 | 1.975 | | | | | | | 45.0 | 2.621 | 70.0 | 3.008 | | |
| 13.0 | 2.059 | | | | | | | 50.0 | 2.746 | | | | |
| 14.0 | 2.142 | | | | | | | | | | | | |
| 15.0 | 2.225 | | | | | | | | | | | | |

positive. Theorem B shows that the integration with respect to time introduces an additional operator p in the denominator to give

$$\bar{Q}_{(p)} = \frac{[I_1(\sqrt{p}\,R)\,K_1(\sqrt{p}\,) - K_1(\sqrt{p}\,R)\,I_1(\sqrt{p}\,)]}{p^{3/2}[K_1(\sqrt{p}\,R)\,I_0(\sqrt{p}\,) + I_1(\sqrt{p}\,R)\,K_0(\sqrt{p}\,)]} \qquad \text{(VII-4)}$$

In order to apply Mellin's inversion formula, the first consideration is the roots of the denominator of this equation which indicate the poles. Since the modified Bessel functions for positive real arguments are either increasing or decreasing, the bracketed term in the denominator does not indicate any poles for positive real values for p. At the origin of the plane of Fig. 2 a pole exists and this pole we shall have to investigate first. Thus, the substitution of small and real values for z (Eqs. VI-12 and VI-13) in Eq. VII-4, gives

$$\lim_{p\to 0} \bar{Q}_{(p)} = \frac{(R^2-1)}{2p}$$

TABLE IV — *Constant Terminal Rate Case Radial Flow*

*Pressure at Exterior Radius Constant*

| R = 1.5<br>$\lambda_1$ = 3.4029<br>$\lambda_2$ = 9.5207 | | R = 2.0<br>$\lambda_1$ = 1.7940<br>$\lambda_2$ = 4.8021 | | R = 2.5<br>$\lambda_1$ = 1.2426<br>$\lambda_2$ = 3.2265 | | R = 3.0<br>$\lambda_1$ = 0.9596<br>$\lambda_2$ = 2.4372 | | R = 3.5<br>$\lambda_1$ = 0.7852<br>$\lambda_2$ = 1.9624 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| $5.0(10)^{-2}$ | 0.230 | $2.0(10)^{-1}$ | 0.424 | $3.0(10)^{-1}$ | 0.502 | $5.0(10)^{-1}$ | 0.617 | $5.0(10)^{-1}$ | 0.620 |
| 5.5 " | 0.240 | 2.2 " | 0.441 | 3.5 " | 0.535 | 5.5 " | 0.640 | 6.0 " | 0.665 |
| 6.0 " | 0.249 | 2.4 " | 0.457 | 4.0 " | 0.564 | 6.0 " | 0.662 | 7.0 " | 0.705 |
| 7.0 " | 0.266 | 2.6 " | 0.472 | 4.5 " | 0.591 | 7.0 " | 0.702 | 8.0 " | 0.741 |
| 8.0 " | 0.282 | 2.8 " | 0.485 | 5.0 " | 0.616 | 8.0 " | 0.738 | 9.0 " | 0.774 |
| 9.0 " | 0.292 | 3.0 " | 0.498 | 5.5 " | 0.638 | 9.0 " | 0.770 | 1.0 | 0.804 |
| $1.0(10)^{-1}$ | 0.307 | 3.5 " | 0.527 | 6.0 " | 0.659 | 1.0 | 0.799 | 1.2 | 0.858 |
| 1.2 " | 0.328 | 4.0 " | 0.552 | 7.0 " | 0.696 | 1.2 | 0.850 | 1.4 | 0.904 |
| 1.4 " | 0.344 | 4.5 " | 0.573 | 8.0 " | 0.728 | 1.4 | 0.892 | 1.6 | 0.945 |
| 1.6 " | 0.356 | 5.0 " | 0.591 | 9.0 " | 0.755 | 1.6 | 0.927 | 1.8 | 0.981 |
| 1.8 " | 0.367 | 5.5 " | 0.606 | 1.0 | 0.778 | 1.8 | 0.955 | 2.0 | 1.013 |
| 2.0 " | 0.375 | 6.0 " | 0.619 | 1.2 | 0.815 | 2.0 | 0.980 | 2.2 | 1.041 |
| 2.2 " | 0.381 | 6.5 " | 0.630 | 1.4 | 0.842 | 2.2 | 1.000 | 2.4 | 1.065 |
| 2.4 " | 0.386 | 7.0 " | 0.639 | 1.6 | 0.861 | 2.4 | 1.016 | 2.6 | 1.087 |
| 2.6 " | 0.390 | 7.5 " | 0.647 | 1.8 | 0.876 | 2.6 | 1.030 | 2.8 | 1.106 |
| 2.8 " | 0.393 | 8.0 " | 0.654 | 2.0 | 0.887 | 2.8 | 1.042 | 3.0 | 1.123 |
| 3.0 " | 0.396 | 8.5 " | 0.660 | 2.2 | 0.895 | 3.0 | 1.051 | 3.5 | 1.158 |
| 3.5 " | 0.400 | 9.0 " | 0.665 | 2.4 | 0.900 | 3.5 | 1.069 | 4.0 | 1.183 |
| 4.0 " | 0.402 | 9.5 " | 0.669 | 2.6 | 0.905 | 4.0 | 1.080 | 5.0 | 1.215 |
| 4.5 " | 0.404 | 1.0 | 0.673 | 2.8 | 0.908 | 4.5 | 1.087 | 6.0 | 1.232 |
| 5.0 " | 0.405 | 1.2 | 0.682 | 3.0 | 0.910 | 5.0 | 1.091 | 7.0 | 1.242 |
| 6.0 " | 0.405 | 1.4 | 0.688 | 3.5 | 0.913 | 5.5 | 1.094 | 8.0 | 1.247 |
| 7.0 " | 0.405 | 1.6 | 0.690 | 4.0 | 0.915 | 6.0 | 1.096 | 9.0 | 1.250 |
| 8.0 " | 0.405 | 1.8 | 0.692 | 4.5 | 0.916 | 6.5 | 1.097 | 10.0 | 1.251 |
| | | 2.0 | 0.692 | 5.0 | 0.916 | 7.0 | 1.097 | 12.0 | 1.252 |
| | | 2.5 | 0.693 | 5.5 | 0.916 | 8.0 | 1.098 | 14.0 | 1.253 |
| | | 3.0 | 0.693 | 6.0 | 0.916 | 10.0 | 1.099 | 16.0 | 1.253 |

TABLE IV — *Continued*

| R = 4.0<br>$\lambda_1$ = 0.6670<br>$\lambda_2$ = 1.6450 | | R = 6.0<br>$\lambda_1$ = 0.4205<br>$\lambda_2$ = 1.0059 | | R = 8.0<br>$\lambda_1$ = 0.3090<br>$\lambda_2$ = 0.7286 | | R = 10<br>$\lambda_1$ = 0.2448<br>$\lambda_2$ = 0.5726 | | R = 15<br>$\lambda_1$ = 0.1616<br>$\lambda_2$ = 0.3745 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 1.0 | 0.802 | 4.0 | 1.275 | 7.0 | 1.499 | 10.0 | 1.651 | 20.0 | 1.960 |
| 1.2 | 0.857 | 4.5 | 1.320 | 7.5 | 1.527 | 12.0 | 1.730 | 22.0 | 2.003 |
| 1.4 | 0.905 | 5.0 | 1.361 | 8.0 | 1.554 | 14.0 | 1.798 | 24.0 | 2.043 |
| 1.6 | 0.947 | 5.5 | 1.398 | 8.5 | 1.580 | 16.0 | 1.856 | 26.0 | 2.080 |
| 1.8 | 0.986 | 6.0 | 1.432 | 9.0 | 1.604 | 18.0 | 1.907 | 28.0 | 2.114 |
| 2.0 | 1.020 | 6.5 | 1.462 | 9.5 | 1.627 | 20.0 | 1.952 | 30.0 | 2.146 |
| 2.2 | 1.052 | 7.0 | 1.490 | 10.0 | 1.648 | 25.0 | 2.043 | 35.0 | 2.218 |
| 2.4 | 1.080 | 7.5 | 1.516 | 12.0 | 1.724 | 30.0 | 2.111 | 40.0 | 2.279 |
| 2.6 | 1.106 | 8.0 | 1.539 | 14.0 | 1.786 | 35.0 | 2.160 | 45.0 | 2.322 |
| 2.8 | 1.130 | 8.5 | 1.561 | 16.0 | 1.837 | 40.0 | 2.197 | 50.0 | 2.379 |
| 3.0 | 1.152 | 9.0 | 1.580 | 18.0 | 1.879 | 45.0 | 2.224 | 60.0 | 2.455 |
| 3.4 | 1.190 | 10.0 | 1.615 | 20.0 | 1.914 | 50.0 | 2.245 | 70.0 | 2.513 |
| 3.8 | 1.222 | 12.0 | 1.667 | 22.0 | 1.943 | 55.0 | 2.260 | 80.0 | 2.558 |
| 4.5 | 1.266 | 14.0 | 1.704 | 24.0 | 1.967 | 60.0 | 2.271 | 90.0 | 2.592 |
| 5.0 | 1.290 | 16.0 | 1.730 | 26.0 | 1.986 | 65.0 | 2.279 | $10.0(10)^1$ | 2.619 |
| 5.5 | 1.309 | 18.0 | 1.749 | 28.0 | 2.002 | 70.0 | 2.285 | 12.0 " | 2.655 |
| 6.0 | 1.325 | 20.0 | 1.762 | 30.0 | 2.016 | 75.0 | 2.290 | 14.0 " | 2.677 |
| 7.0 | 1.347 | 22.0 | 1.771 | 35.0 | 2.040 | 80.0 | 2.293 | 16.0 " | 2.689 |
| 8.0 | 1.361 | 24.0 | 1.777 | 40.0 | 2.055 | 90.0 | 2.297 | 18.0 " | 2.697 |
| 9.0 | 1.370 | 26.0 | 1.781 | 45.0 | 2.064 | $10.0(10)^1$ | 2.300 | 20.0 " | 2.701 |
| 10.0 | 1.376 | 28.0 | 1.784 | 50.0 | 2.070 | 11.0 " | 2.301 | 22.0 " | 2.704 |
| 12.0 | 1.382 | 30.0 | 1.787 | 60.0 | 2.076 | 12.0 " | 2.302 | 24.0 " | 2.706 |
| 14.0 | 1.385 | 35.0 | 1.789 | 70.0 | 2.078 | 13.0 " | 2.302 | 26.0 " | 2.707 |
| 16.0 | 1.386 | 40.0 | 1.791 | 80.0 | 2.079 | 14.0 " | 2.302 | 28.0 " | 2.707 |
| 18.0 | 1.386 | 50.0 | 1.792 | | | 16.0 " | 2.303 | 30.0 " | 2.708 |

and by the application of Mellin's inversion formula applied at the origin, then

$$\frac{1}{2\pi i}\oint_{\lambda=_0} e^{\lambda t}\,\frac{1}{2}\,\frac{(R^2-1)}{\lambda}\,d\lambda=\frac{R^2-1}{2} \quad . \; . \; \text{(VII-5)}$$

An investigation of the integration along the negative real "cut" both for the upper and lower portions, Fig. 2, reveals that Eq. VII-4 is an even function for which the integration along the paths is zero. However, poles are indicated along the negative real axis and these residuals together with Eq. VII-5 make up the solution for the constant terminal pressure case for the limited radial system. The residuals are established by the Mellin's inversion formula by letting $\lambda = u^2 e^{i\pi}$; then by Eqs. VI-18

$$\frac{1}{2\pi i}\oint_{\lambda_1,\,\lambda_2,\,\text{etc.}} e^{\lambda t}\,\bar{Q}(\lambda)\,d\lambda =$$

$$-\frac{1}{\pi i}\oint_{a_1,\,a_2,\,\text{etc.}}\frac{e^{-u^2t}\left[J_1(uR)\;Y_1(u)-Y_1(uR)\;J_1(u)\right]\,du}{u^2\left[J_1(uR)\;Y_o(u)-Y_1(uR)\;J_o(u)\right]} \quad \text{(VII-6)}$$

where $a_1$, $a_2$, and $a_n$ are the roots of

$$\left[J_1(a_nR)\;Y_o(a_n)\;-\;Y_1(a_nR)\;J_o(a_n)\right]\;=\;0 \quad . \quad \text{(VII-7)}$$

and the poles are represented on the negative real axis by $\lambda_n = -a_n^2$, Fig. 3. The residuals of Eq. VII-6 are the series expansion

TABLE IV — *Continued*

| R = 20<br>$\lambda_1$ = 0.1208<br>$\lambda_2$ = 0.2788 | | R = 25<br>$\lambda_1$ = 0.09648<br>$\lambda_2$ = 0.2223 | | R = 30<br>$\lambda_1$ = 0.08032<br>$\lambda_2$ = 0.1849 | | R = 40<br>$\lambda_1$ = 0.06019<br>$\lambda_2$ = 0.1384 | | R = 50<br>$\lambda_1$ = 0.04813<br>$\lambda_2$ = 0.1106 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 30.0 | 2.148 | 50.0 | 2.389 | 70.0 | 2.551 | 12.0(10)¹ | 2.813 | 20.0(10)¹ | 3.064 |
| 35.0 | 2.219 | 55.0 | 2.434 | 80.0 | 2.615 | 14.0 " | 2.888 | 22.0 " | 3.111 |
| 40.0 | 2.282 | 60.0 | 2.476 | 90.0 | 2.672 | 16.0 " | 2.953 | 24.0 " | 3.154 |
| 45.0 | 2.338 | 65.0 | 2.514 | 10.0(10)¹ | 2.723 | 18.0 " | 3.011 | 26.0 " | 3.193 |
| 50.0 | 2.388 | 70.0 | 2.550 | 12.0 " | 2.812 | 20.0 " | 3.063 | 28.0 " | 3.229 |
| 60.0 | 2.475 | 75.0 | 2.583 | 14.0 " | 2.886 | 22.0 " | 3.109 | 30.0 " | 3.263 |
| 70.0 | 2.547 | 80.0 | 2.614 | 16.0 " | 2.950 | 24.0 " | 3.152 | 35.0 " | 3.339 |
| 80.0 | 2.609 | 85.0 | 2.643 | 16.5 " | 2.965 | 26.0 " | 3.191 | 40.0 " | 3.405 |
| 90.0 | 2.658 | 90.0 | 2.671 | 17.0 " | 2.979 | 28.0 " | 3.226 | 45.0 " | 3.461 |
| 10.0(10)¹ | 2.707 | 95.0 | 2.697 | 17.5 " | 2.992 | 30.0 " | 3.259 | 50.0 " | 3.512 |
| 10.5 " | 2.728 | 10.0(10)¹ | 2.721 | 18.0 " | 3.006 | 35.0 " | 3.331 | 55.0 " | 3.556 |
| 11.0 " | 2.747 | 12.0 " | 2.807 | 20.0 " | 3.054 | 40.0 " | 3.391 | 60.0 " | 3.595 |
| 11.5 " | 2.764 | 14.0 " | 2.878 | 25.0 " | 3.150 | 45.0 " | 3.440 | 65.0 " | 3.630 |
| 12.0 " | 2.781 | 16.0 " | 2.936 | 30.0 " | 3.219 | 50.0 " | 3.482 | 70.0 " | 3.661 |
| 12.5 " | 2.796 | 18.0 " | 2.984 | 35.0 " | 3.269 | 55.0 " | 3.516 | 75.0 " | 3.688 |
| 13.0 " | 2.810 | 20.0 " | 3.024 | 40.0 " | 3.306 | 60.0 " | 3.545 | 80.0 " | 3.713 |
| 13.5 " | 2.823 | 22.0 " | 3.057 | 45.0 " | 3.332 | 65.0 " | 3.568 | 85.0 " | 3.735 |
| 14.0 " | 2.835 | 24.0 " | 3.085 | 50.0 " | 3.351 | 70.0 " | 3.588 | 90.0 " | 3.754 |
| 14.5 " | 2.846 | 26.0 " | 3.107 | 60.0 " | 3.375 | 80.0 " | 3.619 | 95.0 " | 3.771 |
| 15.0 " | 2.857 | 28.0 " | 3.126 | 70.0 " | 3.387 | 90.0 " | 3.640 | 10.0(10)² | 3.787 |
| 16.0 " | 2.876 | 30.0 " | 3.142 | 80.0 " | 3.394 | 10.6(10)² | 3.655 | 12.0 " | 3.833 |
| 18.0 " | 2.906 | 35.0 " | 3.171 | 90.0 " | 3.397 | 12.0 " | 3.672 | 14.0 " | 3.862 |
| 20.0 " | 2.929 | 40.0 " | 3.189 | 10.0(10)² | 3.399 | 14.0 " | 3.681 | 16.0 " | 3.881 |
| 24.0 " | 2.958 | 45.0 " | 3.200 | 12.0 " | 3.401 | 16.0 " | 3.685 | 18.0 " | 3.892 |
| 28.0 " | 2.975 | 50.0 " | 3.207 | 14.0 " | 3.401 | 18.0 " | 3.687 | 20.0 " | 3.900 |
| 30.0 " | 2.980 | 60.0 " | 3.214 | | | 20.0 " | 3.688 | 22.0 " | 3.904 |
| 40.0 " | 2.992 | 70.0 " | 3.217 | | | 25.0 " | 3.689 | 24.0 " | 3.907 |
| 50.0 " | 2.995 | 80.0 " | 3.218 | | | | | 26.0 " | 3.909 |
| | | 90.0 " | 3.219 | | | | | 28.0 " | 3.910 |

TABLE IV — *Continued*

| R = 60 | | R = 70 | | R = 80 | | R = 90 | | R = 100 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 3.0(10)² | 3.257 | 5.0(10)² | 3.512 | 6.0(10)² | 3.603 | 8.0(10)² | 3.747 | 1.0(10)³ | 3.859 |
| 4.0 " | 3.401 | 6.0 " | 3.603 | 7.0 " | 3.680 | 9.0 " | 3.806 | 1.2 " | 3.949 |
| 5.0 " | 3.512 | 7.0 " | 3.680 | 8.0 " | 3.747 | 1.0(10)³ | 3.858 | 1.4 " | 4.026 |
| 6.0 " | 3.602 | 8.0 " | 3.746 | 9.0 " | 3.805 | 1.2 " | 3.949 | 1.6 " | 4.092 |
| 7.0 " | 3.676 | 9.0 " | 3.803 | 10.0 " | 3.857 | 1.3 " | 3.988 | 1.8 " | 4.150 |
| 8.0 " | 3.739 | 10.0 " | 3.854 | 12.0 " | 3.946 | 1.4 " | 4.025 | 2.0 " | 4.200 |
| 9.0 " | 3.792 | 12.0 " | 3.937 | 14.0 " | 4.019 | 1.5 " | 4.058 | 2.5 " | 4.303 |
| 10.0 " | 3.832 | 14.0 " | 4.003 | 15.0 " | 4.051 | 1.8 " | 4.144 | 3.0 " | 4.379 |
| 12.0 " | 3.908 | 16.0 " | 4.054 | 16.0 " | 4.080 | 2.0 " | 4.192 | 3.5 " | 4.434 |
| 14.0 " | 3.959 | 18.0 " | 4.095 | 18.0 " | 4.130 | 2.5 " | 4.285 | 4.0 " | 4.478 |
| 16.0 " | 3.996 | 20.0 " | 4.127 | 20.0 " | 4.171 | 3.0 " | 4.349 | 4.5 " | 4.510 |
| 18.0 " | 4.023 | 25.0 " | 4.181 | 25.0 " | 4.248 | 3.5 " | 4.394 | 5.0 " | 4.534 |
| 20.0 " | 4.043 | 30.0 " | 4.211 | 30.0 " | 4.297 | 4.0 " | 4.426 | 5.5 " | 4.552 |
| 25.0 " | 4.071 | 35.0 " | 4.228 | 35.0 " | 4.328 | 4.5 " | 4.448 | 6.0 " | 4.565 |
| 30.0 " | 4.084 | 40.0 " | 4.237 | 40.0 " | 4.347 | 5.0 " | 4.464 | 6.5 " | 4.579 |
| 35.0 " | 4.090 | 45.0 " | 4.242 | 45.0 " | 4.360 | 6.0 " | 4.482 | 7.0 " | 4.583 |
| 40.0 " | 4.092 | 50.0 " | 4.245 | 50.0 " | 4.368 | 7.0 " | 4.491 | 7.5 " | 4.588 |
| 45.0 " | 4.093 | 55.0 " | 4.247 | 60.0 " | 4.376 | 8.0 " | 4.496 | 8.0 " | 4.593 |
| 50.0 " | 4.094 | 60.0 " | 4.247 | 70.0 " | 4.380 | 9.0 " | 4.498 | 9.0 " | 4.598 |
| 55.0 " | 4.094 | 65.0 " | 4.248 | 80.0 " | 4.381 | 10.0 " | 4.499 | 10.0 " | 4.601 |
| | | 70.0 " | 4.248 | 90.0 " | 4.382 | 11.0 " | 4.499 | 12.5 " | 4.604 |
| | | 75.0 " | 4.248 | 10.0(10)³ | 4.382 | 12.0 " | 4.500 | 15.0 " | 4.605 |
| | | 80.0 " | 4.248 | 11.0 " | 4.382 | 14.0 " | 4.500 | | |

$$-2\sum_{\substack{a_1,a_2\\ \text{etc.}}}^{\infty}\frac{e^{-a_n^2 t}\left[J_1(a_nR)\ Y_1(a_n)-Y_1(a_nR)\ J_1(a_n)\right]}{a_n^2\lim_{u\to a_n}\frac{d}{du}\left[J_1(uR)\ Y_0(u)-Y_1(uR)\ J_0(u)\right]} \quad \text{(VII-8)}$$

since

$$J_1'(z)=J_0(z)-J_1(z)/z \quad \text{(VII-9)}$$

and

$$J_0'(z)=-J_1(z)$$

which are recurrence formulae for both first and second kind of Bessel functions, W.B.F., p. 45 and p. 66, then by the identities of Eqs. VII-7 and VI-23, the relation VII-8 reduces to

$$-2\sum_{\substack{a_1,a_2\\ \text{etc.}}}^{\infty}\frac{e^{-a_n^2 t}\ J_1^2\ (a_nR)}{a_n^2\left[J_0^2(a_n)-J_1^2(a_nR)\right]}$$

Therefore, the solution for $Q(t)$ is expressed by

$$Q_{(t)}=\frac{R^2-1}{2}-2\sum_{\substack{a_1,a_2\\ \text{etc.}}}^{\infty}\frac{e^{-a_n^2 t}\ J_1^2(a_nR)}{a_n^2\left[J_0^2(a_n)-J_1^2)a_nR\right)\right]} \quad \text{(VII-10)}$$

This is essentially the solution developed in an earlier work,[8] but Eq. VII-10 is more rapidly convergent than the solution previously reported.

The values of $Q_{(t)}$ for the constant terminal pressure case for a limited reservoir have been calculated from Eq. VII-10 for R = 1.5 to 10 and are tabulated in Table 2. A reproduction of a portion of these data is given in Fig. 5. As Eq. VII-10 is rapidly convergent for t greater than a given value, only two

TABLE IV — *Continued*

| R = 200 | | R = 300 | | R = 400 | | R = 500 | | R = 600 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 1.5(10)³ | 4.061 | 6.0(10)³ | 4.754 | 1.5(10)⁴ | 5.212 | 2.0(10)⁴ | 5.356 | 4.0(10)⁴ | 5.703 |
| 2.0 " | 4.205 | 8.0 " | 4.898 | 2.0 " | 5.356 | 2.5 " | 5.468 | 4.5 " | 5.762 |
| 2.5 " | 4.317 | 10.0 " | 5.010 | 3.0 " | 5.556 | 3.0 " | 5.559 | 5.0 " | 5.814 |
| 3.0 " | 4.408 | 12.0 " | 5.101 | 4.0 " | 5.689 | 3.5 " | 5.636 | 6.0 " | 5.904 |
| 3.5 " | 4.485 | 14.0 " | 5.177 | 5.0 " | 5.781 | 4.0 " | 5.702 | 7.0 " | 5.979 |
| 4.0 " | 4.552 | 16.0 " | 5.242 | 6.0 " | 5.845 | 4.5 " | 5.759 | 8.0 " | 6.041 |
| 5.0 " | 4.663 | 18.0 " | 5.299 | 7.0 " | 5.889 | 5.0 " | 5.810 | 9.0 " | 6.094 |
| 6.0 " | 4.754 | 20.0 " | 5.348 | 8.0 " | 5.920 | 6.0 " | 5.894 | 10.0 " | 6.139 |
| 7.0 " | 4.829 | 24.0 " | 5.429 | 9.0 " | 5.942 | 7.0 " | 5.960 | 12.0 " | 6.210 |
| 8.0 " | 4.894 | 28.0 " | 5.491 | 10.0 " | 5.957 | 8.0 " | 6.013 | 14.0 " | 6.262 |
| 9.0 " | 4.949 | 30.0 " | 5.517 | 11.0 " | 5.967 | 9.0 " | 6.055 | 16.0 " | 6.299 |
| 10.0 " | 4.996 | 40.0 " | 5.606 | 12.0 " | 5.975 | 10.0 " | 6.088 | 18.0 " | 6.326 |
| 12.0 " | 5.072 | 50.0 " | 5.652 | 12.5 " | 5.977 | 12.0 " | 6.135 | 20.0 " | 6.345 |
| 14.0 " | 5.129 | 60.0 " | 5.676 | 13.0 " | 5.980 | 14.0 " | 6.164 | 25.0 " | 6.374 |
| 16.0 " | 5.171 | 70.0 " | 5.690 | 14.0 " | 5.983 | 16.0 " | 6.183 | 30.0 " | 6.387 |
| 18.0 " | 5.203 | 80.0 " | 5.696 | 16.0 " | 5.988 | 18.0 " | 6.195 | 35.0 " | 6.392 |
| 20.0 " | 5.227 | 90.0 " | 5.700 | 18.0 " | 5.990 | 20.0 " | 6.202 | 40.0 " | 6.395 |
| 25.0 " | 5.264 | 10.0(10)⁴ | 5.702 | 20.0 " | 5.991 | 25.0 " | 6.211 | 50.0 " | 6.397 |
| 30.0 " | 5.282 | 12.0 " | 5.703 | 24.0 " | 5.991 | 30.0 " | 6.213 | 60.0 " | 6.397 |
| 35.0 " | 5.290 | 14.0 " | 5.704 | 26.0 " | 5.991 | 35.0 " | 6.214 | | |
| 40.0 " | 5.294 | 15.0 " | 5.704 | | | 40.0 " | 6.214 | | |

TABLE IV — *Continued*

| R = 700 | | R = 800 | | R = 900 | | R = 1000 | | R = 1200 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 5.0(10)⁴ | 5.814 | 7.0(10)⁴ | 5.983 | 8.0(10)⁴ | 6.049 | 1.0(10)⁵ | 6.161 | 2.0(10)⁵ | 6.507 |
| 6.0 " | 5.905 | 8.0 " | 6.049 | 9.0 " | 6.108 | 1.2 " | 6.252 | 3.0 " | 6.704 |
| 7.0 " | 5.982 | 9.0 " | 6.108 | 10.0 " | 6.161 | 1.4 " | 6.329 | 4.0 " | 6.833 |
| 8.0 " | 6.048 | 10.0 " | 6.160 | 12.0 " | 6.251 | 1.6 " | 6.395 | 5.0 " | 6.918 |
| 9.0 " | 6.105 | 12.0 " | 6.249 | 14.0 " | 6.327 | 1.8 " | 6.452 | 6.0 " | 6.975 |
| 10.0 " | 6.156 | 14.0 " | 6.322 | 16.0 " | 6.392 | 2.0 " | 6.503 | 7.0 " | 7.013 |
| 12.0 " | 6.239 | 16.0 " | 6.382 | 18.0 " | 6.447 | 2.5 " | 6.605 | 8.0 " | 7.038 |
| 14.0 " | 6.305 | 18.0 " | 6.432 | 20.0 " | 6.494 | 3.0 " | 6.681 | 9.0 " | 7.056 |
| 16.0 " | 6.357 | 20.0 " | 6.474 | 25.0 " | 6.587 | 3.5 " | 6.738 | 10.0 " | 7.067 |
| 18.0 " | 6.398 | 25.0 " | 6.551 | 30.0 " | 6.652 | 4.0 " | 6.781 | 12.0 " | 7.080 |
| 20.0 " | 6.430 | 30.0 " | 6.599 | 40.0 " | 6.729 | 4.5 " | 6.813 | 14.0 " | 7.085 |
| 25.0 " | 6.484 | 35.0 " | 6.630 | 45.0 " | 6.751 | 5.0 " | 6.837 | 16.0 " | 7.088 |
| 30.0 " | 6.514 | 40.0 " | 6.650 | 50.0 " | 6.766 | 5.5 " | 6.854 | 18.0 " | 7.089 |
| 35.0 " | 6.530 | 45.0 " | 6.663 | 55.0 " | 6.777 | 6.0 " | 6.868 | 19.0 " | 7.089 |
| 40.0 " | 6.540 | 50.0 " | 6.671 | 60.0 " | 6.785 | 7.0 " | 6.885 | 20.0 " | 7.090 |
| 45.0 " | 6.545 | 55.0 " | 6.676 | 70.0 " | 6.794 | 8.0 " | 6.895 | 21.0 " | 7.090 |
| 50.0 " | 6.548 | 60.0 " | 6.679 | 80.0 " | 6.798 | 9.0 " | 6.901 | 22.0 " | 7.090 |
| 60.0 " | 6.550 | 70.0 " | 6.682 | 90.0 " | 6.800 | 10.0 " | 6.904 | 23.0 " | 7.090 |
| 70.0 " | 6.551 | 80.0 " | 6.684 | 10.0(10)⁵ | 6.801 | 12.0 " | 6.907 | 24.0 " | 7.090 |
| 80.0 " | 6.551 | 100.0 " | 6.684 | | | 14.0 " | 6.907 | | |
| | | | | | | 16.0 " | 6.908 | | |

terms of the expansion are necessary to give the accuracy needed in the calculations.

Likewise from the foregoing work it can be easily shown that the transform of the pressure drop at any point in the formation in a limited reservoir for the constant terminal rate case, is expressed by

$$\bar{P}_{(r,p)} = \frac{[K_1(\sqrt{p}\,R)\,I_0(\sqrt{p}\,r) + I_1(\sqrt{p}\,R)\,K_0(\sqrt{p}\,r)]}{p^{3/2}[I_1(\sqrt{p}\,R)\,K_1(\sqrt{p}\,) - K_1(\sqrt{p}\,R)\,I_1\sqrt{p}\,)]} \qquad \text{(VII-11)}$$

An examination of the denominator of Eq. VII-11 indicates that there are no roots for positive values of p. However, a double pole exists at $p = 0$. This can be determined by expanding $K_0(z)$ and $K_1(z)$ to second degree expansions for small values of z and third degree expansions for $I_0(z)$ and $I_1(z)$, and substituting in Eq. VII-11. It is found for small values of p, Eq. VII-11 reduces to

$$\bar{P}_{\substack{(r,p)\\ p\to 0}} = \frac{1}{p}\left\{\frac{R^2}{(R^2-1)}\log\frac{R}{r} - \frac{(R^2-r^2)}{2(R^2-1)} + \frac{R^2\log R}{(R^2-1)^2} - \frac{(R^2+1)}{4(R^2-1)^2}\right\} + \frac{1}{p^2}\frac{2}{(R^2-1)} \qquad \text{(VII-12)}$$

This equation now indicates both a single and double pole at the origin, and it can be shown from tables or by applying Cauchy's theorem to the Mellin's formula that the inversion of Eq. VII-12 is

$$P_{(r,t)} = \frac{2}{(R^2-1)}\left[\frac{r^2}{4} + t\right] - \frac{R^2}{(R^2-1)}\log r - \frac{[3R^4-4R^4\log R-2R^2-1]}{4(R^2-1)^2} \qquad \text{(VII-13)}$$

which holds when the time, t, is large

As in the preceding case, there are poles along the negative real axis, Fig. 3, and the residuals are determined as before by letting $\lambda = u^2 e^{i\pi}$, and Eqs. VI-18 give

TABLE IV — *Continued*

| R = 1400 | | R = 1600 | | R = 1800 | | R = 2000 | | R = 2200 | |
|---|---|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 2.0(10)$^5$ | 6.507 | 2.5(10)$^5$ | 6.619 | 3.0(10)$^5$ | 6.710 | 4.0(10)$^5$ | 6.854 | 5.0(10)$^5$ | 6.966 |
| 2.5 " | 6.619 | 3.0 " | 6.710 | 4.0 " | 6.854 | 5.0 " | 6.966 | 5.5 " | 7.013 |
| 3.0 " | 6.709 | 3.5 " | 6.787 | 5.0 " | 6.965 | 6.0 " | 7.056 | 6.0 " | 7.057 |
| 3.5 " | 6.785 | 4.0 " | 6.853 | 6.0 " | 7.054 | 7.0 " | 7.132 | 6.5 " | 7.097 |
| 4.0 " | 6.849 | 5.0 " | 6.962 | 7.0 " | 7.120 | 8.0 " | 7.196 | 7.0 " | 7.133 |
| 5.0 " | 6.950 | 6.0 " | 7.046 | 8.0 " | 7.188 | 9.0 " | 7.251 | 7.5 " | 7.167 |
| 6.0 " | 7.026 | 7.0 " | 7.114 | 9.0 " | 7.238 | 10.0 " | 7.298 | 8.0 " | 7.199 |
| 7.0 " | 7.082 | 8.0 " | 7.167 | 10.0 " | 7.280 | 12.0 " | 7.374 | 8.5 " | 7.229 |
| 8.0 " | 7.123 | 9.0 " | 7.210 | 15.0 " | 7.407 | 14.0 " | 7.431 | 9.0 " | 7.256 |
| 9.0 " | 7.154 | 10.0 " | 7.244 | 20.0 " | 7.459 | 16.0 " | 7.474 | 10.0 " | 7.307 |
| 10.0 " | 7.177 | 15.0 " | 7.334 | 30.0 " | 7.489 | 18.0 " | 7.506 | 12.0 " | 7.390 |
| 15.0 " | 7.229 | 20.0 " | 7.364 | 40.0 " | 7.495 | 20.0 " | 7.530 | 16.0 " | 7.507 |
| 20.0 " | 7.241 | 25.0 " | 7.373 | 50.0 " | 7.495 | 25.0 " | 7.566 | 20.0 " | 7.579 |
| 25.0 " | 7.243 | 30.0 " | 7.376 | 51.0 " | 7.495 | 30.0 " | 7.584 | 25.0 " | 7.631 |
| 30.0 " | 7.244 | 35.0 " | 7.377 | 52.0 " | 7.495 | 35.0 " | 7.593 | 30.0 " | 7.661 |
| 31.0 " | 7.244 | 40.0 " | 7.378 | 53.0 " | 7.495 | 40.0 " | 7.597 | 35.0 " | 7.677 |
| 32.0 " | 7.244 | 42.0 " | 7.378 | 54.0 " | 7.495 | 50.0 " | 7.600 | 40.0 " | 7.686 |
| 33.0 " | 7.244 | 44.0 " | 7.378 | 56.0 " | 7.495 | 60.0 " | 7.601 | 50.0 " | 7.693 |
| | | | | | | 64.0 " | 7.601 | 60.0 " | 7.695 |
| | | | | | | | | 70.0 " | 7.696 |
| | | | | | | | | 80.0 " | 7.696 |

TABLE IV — *Continued*

| R = 2400 | | R = 2600 | | R = 2800 | | R = 3000 | |
|---|---|---|---|---|---|---|---|
| t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ | t | $P_{(t)}$ |
| 6.0(10)$^5$ | 7.057 | 7.0(10)$^5$ | 7.134 | 8.0(10)$^5$ | 7.201 | 1.0(10)$^6$ | 7.312 |
| 7.0 " | 7.134 | 8.0 " | 7.201 | 9.0 " | 7.260 | 1.2 " | 7.403 |
| 8.0 " | 7.200 | 9.0 " | 7.259 | 10.0 " | 7.312 | 1.4 " | 7.480 |
| 9.0 " | 7.259 | 10.0 " | 7.312 | 12.0 " | 7.403 | 1.6 " | 7.545 |
| 10.0 " | 7.310 | 12.0 " | 7.401 | 16.0 " | 7.542 | 1.8 " | 7.602 |
| 12.0 " | 7.398 | 14.0 " | 7.475 | 20.0 " | 7.644 | 2.0 " | 7.651 |
| 16.0 " | 7.526 | 16.0 " | 7.536 | 24.0 " | 7.719 | 2.4 " | 7.732 |
| 20.0 " | 7.611 | 18.0 " | 7.588 | 28.0 " | 7.775 | 2.8 " | 7.794 |
| 24.0 " | 7.668 | 20.0 " | 7.631 | 30.0 " | 7.797 | 3.0 " | 7.820 |
| 28.0 " | 7.706 | 24.0 " | 7.699 | 35.0 " | 7.840 | 3.5 " | 7.871 |
| 30.0 " | 7.720 | 28.0 " | 7.746 | 40.0 " | 7.870 | 4.0 " | 7.908 |
| 35.0 " | 7.745 | 30.0 " | 7.765 | 50.0 " | 7.905 | 4.5 " | 7.935 |
| 40.0 " | 7.760 | 35.0 " | 7.799 | 60.0 " | 7.922 | 5.0 " | 7.955 |
| 50.0 " | 7.775 | 40.0 " | 7.821 | 70.0 " | 7.930 | 6.0 " | 7.979 |
| 60.0 " | 7.780 | 50.0 " | 7.845 | 80.0 " | 7.934 | 7.0 " | 7.992 |
| 70.0 " | 7.782 | 60.0 " | 7.856 | 90.0 " | 7.936 | 8.0 " | 7.999 |
| 80.0 " | 7.783 | 70.0 " | 7.860 | 10.0(10)$^6$ | 7.937 | 9.0 " | 8.002 |
| 90.0 " | 7.783 | 80.0 " | 7.862 | 12.0 " | 7.937 | 10.0 " | 8.004 |
| 95.0 " | 7.783 | 90.0 " | 7.863 | 13.0 " | 7.937 | 12.0 " | 8.006 |
| | | 10.0(10)$^6$ | 7.863 | | | 15.0 " | 8.005 |

$$\frac{1}{2\pi i}\oint_{\lambda_1,\lambda_2,\text{ etc.}} e^{\lambda t}\,\overline{P}_{(r,\lambda)}\,d\lambda = \frac{1}{\pi i}\oint_{\beta_1,\beta_2,\text{ etc.}} \frac{e^{-u^2t}\,[J_1(uR)\ Y_o(ur) - Y_1(uR)\ J_o(ur)]\,du}{u^2[J_1(uR)\ Y_1(u) - J_1(u)\ Y_1(uR)]} \quad \text{(VII-14)}$$

where $\beta_1$, $\beta_2$, etc., are roots of

$$[J_1(\beta_n R)\ Y_1(\beta_n) - J_1(\beta_n)\ Y_1(\beta_n R)] = 0 \quad \text{(VII-15)}$$

with $\lambda_n = -\beta_n^2$. The residuals at the poles in Eq. VII-14 give the series

$$2\sum_{\beta_1,\beta_2,\text{ etc.}}^{\infty} \frac{e^{-\beta_n^2 t}\,[J_1(\beta_n R)\ Y_o(\beta_n r) - Y_1(\beta_n R)\ J_o(\beta_n)]}{\beta_n^2 \lim_{u\to\beta_n}\frac{d}{du}[J_1(uR)\ Y_1(u) - J_1(u)\ Y_1(uR)]} \quad \text{(VII-16)}$$

By the recurrence formulae Eqs. VII-9, the identity VII-15, and Eq. VI-23, this series simplifies to

$$\pi\sum_{\beta_1,\beta_2,\text{ etc.}}^{\infty} \frac{e^{-\beta_n^2 t}\,J_1(\beta_n R)\,[J_1(\beta_n)\ Y_o(\beta_n r) - Y_1(\beta_n)\ J_o(\beta_n r)]}{\beta_n[J_1^2(\beta_n R) - J_1^2(\beta_n)]} \quad \text{(VII-17)}$$

Therefore, the sum of all residuals, Eqs. VII-13 and VII-17 is the solution for the cumulative pressure drop at any point in the formation for the constant terminal rate case in a limited reservoir, or

$$P_{(r,t)} = \frac{2}{(R^2-1)}\left(\frac{r^2}{4}+t\right) - \frac{R^2}{(R^2-1)}\log r - \frac{(3R^4-4R^4\log R-2R^2-1)}{4(R^2-1)^2} + \sum_{\beta_1,\beta_2}^{\infty}\pi\,\frac{e^{-\beta_n^2 t}\,J_1^2(\beta_n R)\,[J_1(\beta_n)\ Y_o(\beta_n r) - Y_1(\beta_n)\ J_o(\beta_n r)]}{\beta_n[J_1^2(\beta_n R) - J_1^2(\beta_n)]} \quad \text{(VII-18)}$$

which is essentially the solution given by Muskat,[4] now developed by the Laplace Transformation. Finally, for the cumulative pressure drop for a unit rate of production at the well bore, r = 1, this relation simplifies to

$$P_{(t)} = \frac{2}{(R^2-1)}\left(\frac{1}{4}+t\right) - \frac{(3R^4-4R^4\log R-2R^2-1)}{4(R^2-1)^2} + 2\sum_{\beta_1,\beta_2}^{\infty}\frac{e^{-\beta_n^2 t}\,J_1^2(\beta_n R)}{\beta_n^2[J_1^2(\beta_n R) - J_1^2(\beta_n)]} \quad \text{(VII-19)}$$

The calculations for the constant terminal rate case for a reservoir of limited radial extent have been determined from Eq. VII-19. The summary data for R = 1.5 to 10 are given in Table 3. An illustrative graph is shown in Fig. 6. The effect of the limited reservoir is quite pronounced as it is shown that producing the reservoir at a unit rate increases the pressure drop at the well bore much faster than if the reservoir were infinite, as the constant withdrawal of fluid is reflected very soon in the productive life by the constant rate of drop in pressure with time.

### *Pressure Fixed at Exterior Boundary*

As a variation on the condition that $\left(\frac{dP}{dr}=0\right)_{r=R}$ we may assume that the pressure at r = R is constant. In effect, this assumption helps to explain approximately the pressure history of flowing a well at a constant rate when, upon opening, the bottom hole pressure drops very rapidly and then levels out to become constant with time. The case has been developed by Hurst[3] using a cylinder source and by Muskat[4] using a point source solution.

When developing the solution by means of the Laplace transformation, it is assumed that the exterior boundary r = R, $\overline{P}(R,p) = 0$, which fixes the pressure at the exterior boundary as constant. Since the above-quoted references contain complete details, the final solutions are only quoted here for completeness' sake.

Cylindrical source:

$$P_{(t)} = \log R - 2\sum_{n=1}^{\infty}\frac{e^{-\lambda_n^2 t}\,J_o^2(\lambda_n R)}{\lambda_n^2[J_1^2(\lambda_n) - J_o^2(\lambda_n R)]} \quad \text{(VII-20)}$$

where $\lambda_n$ is the root established from

$$J_1(\lambda_n)\ Y_o(\lambda_n R) - Y_1(\lambda_n)\ J_o(\lambda_n R) = 0 \quad \text{(VII-21)}$$

Point source:

$$P_{(t)} = \log R - \frac{2}{R^2}\sum_{n=1}^{\infty}\frac{e^{-\mu_n^2 t}\,J_o(\mu_n)}{\mu_n^2 J_1^2(\mu_n R)} \quad \text{(VII-22)}$$

where the root $\mu_n$ is determined from $J_o(\mu_n R) = 0$, W.B.F., p. 748. Table 4 is the summary of the calculated P(t) employing Eq. VII-20 for R = 1.5 to 50, the cylinder source solution, which applies for small as well as large times. The data given for R = 60 to 3,000 are calculated from the point source solution Eq. VII-22. Plots of these data are given in Fig. 7.

## SPECIAL PROBLEMS

The work that has gone before shows the facility of the Laplace transformation in deriving analytical solutions. Not yet shown is the versatility of the Laplace transformation in arriving at solutions which are not easily foreseen by the orthodox methods. One such solution derived here has shown to be of value in the analysis of flow tests.

When making flow tests on a well, it is often noticed that the production rates, as measured by the fluid accumulating in the stock tanks, are practically constant. Since it is desired to obtain the relation between flowing bottom hole pressure and the rate of production from the formation, it is necessary to correct the rate of production as measured in the flow tanks for the amount of oil obtained from the annulus between casing and tubing. To arrive at the solution for this problem, we use the basic equation for the constant terminal rate case given by Eq. IV-11, where $q_{(T)}$ is the constant rate of fluid produced at the stock tank corrected to reservoir conditions, but $P_{(t)}$ is a pseudo pressure drop which is adjusted mathematically for the unloading of the fluid from the annulus to give the pressure drop occurring in the formation.

It is assumed that the unloading of the annulus is directly reflected by the change in bottom hole pressure as exerted by a hydrostatic head of oil column in the casing. Therefore, the rate of unloading of the annulus $q_{A(T)}$, expressed in cc. per second corrected to reservoir conditions, is equal to

$$q_{A(T)} = C\frac{d\triangle P}{dT} \quad \text{(VIII-1)}$$

where C is the volume of fluid unloaded from the annulus per atmosphere bottom hole pressure drop per unit sand thickness. The rate of fluid produced from the formation is then given by $q_{(T)} - q_{A(T)}$. As the bottom hole pressure is continuously changing, the problem becomes one of a variable rate. The substitution of the form of Eq. IV-11 in the superposition theorem, Eq. IV-16, gives

$$\Delta P = \frac{\mu}{2\pi K} \int_0^t [q_{(\tau')} - q_{A(\tau')}]\, P'_{(t-t')}\, dt'$$

and from Eq. VIII-1

$$\Delta P = \frac{\mu}{2\pi K} \int_0^t \left[ q_{(\tau')} - C \frac{d\Delta P}{dT'} \right] P'_{(t-t')}\, dt' \quad . \quad \text{(VIII-2)}$$

Since $T = f\mu c R_b^2\, t/K$, and the unit rate of production at the surface corrected to reservoir conditions is $\underline{q}_{(t)} = \frac{\underline{q}_{(\tau)}\mu}{2\pi K}$, Eq. VIII-2 becomes

$$\Delta P = \int_0^t \left[ q_{(t')} - \overline{C} \frac{d\Delta P}{dt'} \right] P'_{(t-t')}\, dt' \quad . \quad \text{(VIII-3)}$$

where $\overline{C} = C/2\pi f c R_b^2$.

Eq. VIII-3 presents a unique situation and we are confronted with determination of $\Delta P$, the actual pressure drop, appearing both in the integrand and to the left side of the equation. The Laplace transformation offers a means of solving for $\Delta P$ which, by orthodox methods, would be difficult to accomplish.

It will be recognized that Theorem D, from Chapter V, is applicable. Therefore, if Eq. VIII-3 can be changed to a Laplace transformation, $\Delta P$ can be solved explicitly. If we express the transform of the constant rate $q_{(t)}$ as $q/p$, the transform of $P'_{(t)}$ as $p\overline{P}_{(p)}$ and the transform of $\Delta P$ as $\Delta\overline{P}$, so that the transform for $d\Delta P/dt$ is $p\Delta\overline{P}$, then it follows that

$$\Delta\overline{P} = \left[ \frac{q}{p} - \overline{C}\, p\Delta\overline{P} \right] p\, \overline{P}_{(p)} \quad . \quad \text{(VIII-4)}$$

and on solution gives

$$\Delta\overline{P} = \frac{q\, \overline{P}_{(p)}}{[1 + \overline{C}\, p^2 \overline{P}_{(p)}]} \quad . \quad \text{(VIII-5)}$$

Since $q = q_{(T)}\mu/2\pi K$, then the term $\dfrac{\overline{P}_{(p)}}{[1 + \overline{C}\, p^2 \overline{P}_{(p)}]}$ in Eq. VIII-5 can be interpreted as the transform of the pseudo pressure drop for the unit rate of production at the stock tank.

No mention has been made as to what value can be substituted for $\overline{P}_{(p)}$. If we wish to apply the cylinder source, Eq. VI-4 applies, namely,

$$\overline{P}_{(p)} = \frac{K_o(\sqrt{p})}{p^{3/2}\, K_1(\sqrt{p})} \quad . \quad \text{(VIII-6)}$$

However, from the previous discussion it has been shown that for wells, t is usually large since the well radius is small, and the point source solution of Lord Kelvin's applies, namely,

$$P_{(t)} = \frac{1}{2} \int_{1/4\,t}^{\infty} \frac{e^{-u}}{u}\, du \quad . \quad \text{(VI-16)}$$

the Ei-function. Therefore, to apply this expression in Eq. VIII-5, it is necessary to obtain the Laplace transform of the point source solution of Eq. VI-16. By an interchange of variables, this equation becomes

$$P_{(t)} = \frac{1}{2} \int_0^t \frac{e^{-1/4t}}{t}\, dt \quad . \quad \text{(VIII-7)}$$

and it will be recognized from Campbell and Foster, Eq. 920.1, that the integrand is the transform for $K_o(\sqrt{p})$. Further, the integration with respect to time follows from Theorem B, Chapter V, so that the transform of Eq. VIII-7 is the relation

$$\overline{P}_{(p)} = \frac{K_o(\sqrt{p})}{p} \quad . \quad \text{(VIII-8)}$$

The same result can be gleaned from Eq. VIII-6 since for t large, p is small and $K_1(\sqrt{p}) = 1/\sqrt{p}$. Substitution of this approximation in Eq. VIII-6 yields Eq. VIII-8. Therefore, introducing the expression for $\overline{P}_{(p)}$ in Eq. VIII-5 gives

$$\Delta\overline{P} = \frac{q\, K_o(\sqrt{p})}{p\,[1 + \overline{C}\, p\, K_o(\sqrt{p})]} \quad . \quad \text{(VIII-9)}$$

for which it is necessary only to find the inverse of

$$\frac{K_o(\sqrt{p})}{p\,[1 + \overline{C}\, p\, K_o(\sqrt{p})]} \quad . \quad . \quad . \quad \text{(VIII-10)}$$

to obtain values for $P_{(t)}$; the cumulative pressure drop for unit rate of production in the stock tank which automatically takes cognizance of the unloading of the annulus.

The inverse of the form of VIII-10 by the Mellin's inversion formula can be determined by the path described in Fig. 2. The analytical determination is identical with the constant terminal rate case given in Section VI. Therefore, the cumulative pressure drop in the well bore, for a unit rate of production at the surface, corrected for the unloading of the fluid in the casing, is the relation

$$P_{(t)} = \int_0^{\infty} \frac{(1 - e^{-u^2 t})\, J_o(u)\, du}{u\left[ \left(1 + u^2 \overline{C} \frac{\pi}{2} Y_o(u)\right)^2 + \left(u^2 \overline{C} \frac{\pi}{2} J_o(u)\right)^2 \right]} \quad \text{(VIII-11)}$$

Fig. 8 presents a plot of the computed values for $P_{(t)}$ corresponding to $\overline{C}$ from 1,000 to 75,000. It can be observed that the greater the unloading from the casing, the smaller the actual pressure drop is in a formation due to the reduced rate of fluid produced from the sand. For large times, however, all curves become identified with the point source solution which is the envelope of these curves. After a sufficient length of time, the change in bottom hole pressure is so slow that the rate of production from the formation is essentially that produced by the well, and the point source solution applies.

## ACKNOWLEDGMENTS

The authors wish to thank the Management of the Shell Oil Co., for permission to prepare and present this paper for publication. It is hoped that this information, once available to the industry, will further the analysis and understanding of the behavior of oil reservoirs.

The authors acknowledge the help of H. Rainbow of the Shell Oil Co., whose suggestions on analytic development were most helpful, and of Miss L. Patterson, who contributed the greatest amount of these calculations with untiring effort.

## REFERENCES

1. "Water Influx into a Reservoir and Its Application to the Equation of Volumetric Balance," William Hurst, *Trans.*, AIME, 1943.

2. "Analysis of Reservoir Performance," R. E. Old, *Trans.*, AIME, 1943.

3. "Unsteady Flow of Fluids in Oil Reservoirs," William Hurst, *Physics*, January, 1934.

4. "The Flow of Compressible Fluids Through Porous Media and Some Problems in Heat Conduction," M. Muskat, *Physics*, March, 1934.

5. *Mathematical Methods in Engineering*, Karman and Biot, p. 403, McGraw-Hill, 1940.

6. *Operational Circuit Analysis*, Vannevar Bush, Chapter V, John Wiley and Sons, 1929.

7. "Variations in Reservoir Pressure in the East Texas Field," R. J. Schilthuis and W. Hurst, *Trans.*, AIME, 1935.

8. "Fourier Integrals for Practical Applications," G. A. Campbell and R. M. Foster, American Telephone and Telegraph Company.

9. *Operational Methods in Applied Mathematics*, H. S. Carslaw and J. C. Jaeger, Oxford Univ. Press, 1941. (Chapter IV).

10. *Ibidum.* p. 5 to 7.

11. "A Problem in the Theory of Heat Conduction," J. W. Nicholsen, p. 226, Proc. Royl. Soc., 1921.

12. "Some Two-Dimensional Diffusion Problems with Circular Symmetry," S. Goldstein, p. 51, Proc. London Math. Soc. (2), Vol. XXXIV, 1932.

13. "Heat Flow in an Infinite Solid Bounded Internally by a Cylinder," L. P. Smith, p. 441, *J. App. Physics*, 8, 1937.

14. "Some Two-Dimensional Problems in Conduction of Heat with Circular Symmetry," H. S. Carslaw and J. C. Jaeger, p. 361, Proc. London Math. Soc. (2), Vol. XIVI.

15. "Heat Flow in the Region Bounded Internally by a Circular Cylinder," J. C. Jaeger, p. 223, Proc. Royal Soc., Edinb. A, 61, 1942.

16. *A Treatise on the Theory of Bessel Functions*, G. W. Watson, Cambridge Univ. Press, 1944.

17. *Modern Analysis*, E. T. Whittaker and G. W. Watson, Cambridge Univ. Press, 1944.

18. *The Conduction of Heat*, H. S. Carslaw, pp. 149-153, MacMillan and Company, 1921.

19. "Pressure Prediction for Oil Reservoirs," W. A. Bruce, *Trans.*, AIME, 1943.

20. "Reservoir Performance and Well Spacing," Lincoln F. Elkins, *Oil and Gas Journal*, Nov. 16, 1946, API, 1946.

21. *Conduction of Heat in Solids*, H. S. Carslaw and J. C. Jaeger, Oxford at the Clarendon Press, 1947.

*Note:* This book came to our notice only after the text of this paper was prepared and for that reason references to its contents are incomplete. The careful reader will observe that, for instance, equation VI-21 in this paper is similar to equation (16), p. 283 when k and a are given unit values; also that "Limited Reservoirs" contains equations quite similar to those appearing in Section 126, "The Hollow Cylinder," of Carslaw and Jaeger's book. ★ ★ ★

## DISCUSSION

*Comments on "The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks," by H. F. Dunlap, H. L. Bilhartz, Ellis Shuler, and C. R. Bailey. Published in the October, 1949 issue of the* JOURNAL OF PETROLEUM TECHNOLOGY.

*By G. E. Archie, Shell Oil Co., Houston, Texas*

I wish to compliment the authors on their experimental work of measuring the resistivities of cores. Measurements of this nature are difficult, particularly on small core samples.

The conclusion that the saturation exponent, n, used when interpreting electrical logs, varies appreciably from 2.0 does not follow from the data. It is true that individual samples indicated an n value considerably different, for instance, the Strawn sandstone given in Table 1 where n = 1.18. Rocks are heterogeneous, however, and more than one sample must be measured. One sample is of little value in predicting any property of the formation as a whole; therefore, only data where several pieces of the formation have been analyzed can be considered conclusive to be used to predict a value for n. Of the data presented in this paper, the measurements made on the Cotton Valley sandstone seem to meet this requirement, see Table I, where six samples were measured. The average value of n equals 1.8. This value cannot be said to vary appreciably from 2.0. (It is true that n varied from 1.5 to 2.0, but experimental error variations on the same sample were 1.7 to 2.0, see sample No. 6, Table I.) In view of the experimental error involved and the limited number of analyses run, the more logical conclusion would be that the data on the Cotton Valley sandstone give weight to the assumption that n may be expected to be of the order of 2.0 for sandstones.

This later data, together with the data given on a chart presented with my comments on the paper, "Estimation of Interstitial Water from the Electrical Log," by Milton Williams, also presented at the San Antonio meeting, indicates that the *average* value of n for consolidated sandstone "in situ" may be closer to 1.9 than 2.0 which has formerly been used. ★ ★ ★

*Author's Reply to G. E. Archie—*

The average of all of our own measurements on saturation exponents for various consolidated sandstone and limestone cores is about 1.75, and, as Archie properly points out, the scatter in the determinations on cores taken from a single formation is considerable. However, we have never measured a saturation exponent for a consolidated core which was significantly greater than two, and the great majority are somewhat less, the lowest value measured being that of 1.17 for the Strawn sandstone sample reported in the paper. For unconsolidated material, the values have usually been two or above. Exactly what the most nearly correct average value to use of consolidated sandstones would be is difficult to estimate in view of the limited data available, but we would estimate a value of 1.7 to 1.8 rather than 1.9 to 2.0. However, more data might well change this average value. For formations of particular interest, it is believed desirable to determine an average exponent from measurements on a number of core samples rather than to use any assumed universal average value. The fact that variation could occur, rather than the use of any particular average number for the exponent, was the thesis of the paper. ★ ★ ★

## DISCUSSION

*Comments on "The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks" by H. F. Dunlap, H. L. Bilhartz, Ellis Shuler and C. R. Bailey. Published in the October, 1949 issue of Journal of Petroleum Technology.*

*By M. R. J. Wyllie and Walter D. Rose, Gulf Research and Development Company, Pittsburgh, Pennsylvania*

This paper and the results it gives concerning the numerical value of the exponent n in the resistivity index-saturation relationship, $I = S_w^{-n}$, is a most valuable and timely contribution to the rather sparse literature on a subject vital to electric log interpretation. Inasmuch as the results obtained provide some opportunity for checking certain theoretical conclusions we reached in a recent paper,[1] it is of particular interest to us.

The results obtained by the authors clearly show that the exponent n is not a constant with a value of about 2.0 as is generally assumed, but varies from core to core and may thus be considered some function of rock texture. On the basis of our theoretical development, we forecast that the exponent n would vary with rock texture (as measured in terms of irreducible wetting phase saturation, $S_{wi}$) and with saturation of the wetting phase itself. It is the latter prediction which is denied by Dunlap et al when they explicitly state that the available evidence indicates that the saturation exponent, n, does not vary with saturation. While we would like to believe this to be true (since an exponent n which was always independent of saturation, if albeit dependent upon rock texture, would introduce one welcome simplification in a complex problem) we do not believe that this is the only interpretation of all the results extant, including those of Dunlap et al. The results of Wyckoff and Botset,[2] Leverett[4] and other workers on essentially unconsolidated sands do indeed show a relatively constant exponent n, but those of Morse, Terwilliger and Yuster[5] and those of the Russian workers quoted by Guyod[6] show a marked dependence of n on saturation in certain instances. The variation of the exponent n with saturation shown in Fig. 5 of the paper of Dunlap et al is apparently attributed by these workers to non-equilibrium conditions. Elsewhere, however, it is stated that when, at high desaturating pressures and apparent equilibrium, widely varying values of the saturation exponent were found in different parts of the core, the results were considered unreliable and not reported.

We have shown[1] that an analytical expression for the exponent n can be found of the form:

$$n = \frac{\ln S_w^2 \, T/T_e}{\ln S_w^2},$$

Where,

$S_w$ = the wetting phase saturation as a fraction of the pore volume,

$T$ = the tortuosity of the porous medium at 100 per cent wetting phase saturation, and is defined as the square of the ratio of mean actual pore length to bed length,

$T_e$ = the effective tortuosity, similarly defined, for the saturation, $S_w$.

From the above expression if n is to be a constant independent of saturation, it follows that $T/T_e = S_w^{x-2}$, where x is a constant having the value 2n. The ratio $T/T_e$ is itself a measure of fluid distribution and may be expected to vary somewhat with the manner in which a particular saturation has been obtained. Thus, the fact that the exponent n for a Strawn sandstone sample was found by Dunlap et al to vary when the mode of saturation was changed from flooding to capillary pressure desaturation is quite explicable in terms of a variation in the $T/T_e$ ratio at a particular saturation. That the ratio $T/T_e$ for any particular mode of saturating or desaturating a porous medium should be uniquely related to the degree of saturation by an expression of the form $T/T_e = S_w^{x-2}$ appears to us to be possible in certain cases, but we see no reason to believe that this relationship is universally true of all porous media. In particular we would expect to find pore size distribution as a big factor in determining $T/T_e$, since the tendency for the wetting phase to be displaced first from the larger pores by an entering non-wetting phase must necessarily affect $T/T_e$ in a manner which is not always expressible in terms of $S_w^{x-2}$ with x a constant.

We would thus like to ask Dunlap and his co-workers whether upon further consideration they are convinced that there is never a genuine variation of the exponent n with saturation. In addition, we would be interested to learn whether any of the results discarded because of their apparent unreliability showed apparent values of n between 3 and 4.5, i.e., in a range covering certain observations made by Williams and by the Russian workers quoted by Guyod and considered possible by us on theoretical grounds. In general, however, it would appear that to a first approximation and in the absence of more specific knowledge a value for n of about 2.0 - 2.5 is still the best average value to assume for log interpretation. In the light of the results reported by Williams we would particularly query the conclusion that n is generally less than 2 for consolidated media.

### REFERENCES

1. "Some Theoretical Considerations Related to the Quantitative Evaluation of the Physical Characteristics of Reservoir Rock from Electrical Log Data." M. R. J. Wyllie and Walter D. Rose. (Submitted for publication in the *Jour. of Petr. Tech.*)

2. "Estimation of Interstitial Water from the Electric Log." M. Williams. AIME, San Antonio, Oct. 7, 1949.

3. "The Flow of Gas-Liquid Mixtures through Unconsolidated Sands." R. D. Wyckoff and H. G. Botset. *Physics*, 7, (9), 325, (1936).

4. "Flow of Oil-Water Mixtures through Unconsolidated Sands." M. C. Leverett. *Trans.* AIME, 132, 149, (1939).

5. "Relative Permeability Measurements on Small Core Samples." R. A. Morse, P. L. Terwilliger and S. T. Yuster. *Oil and Gas Jour.*, 46, (16), 109, (1947).

6. "Electrical Logging Developments in the U.S.S.R.": Part 6. H. Guyod, *World Oil*, 128 (4), 110, (1948). ★ ★ ★

*Author's Reply to M. R. J. Wyllie and Walter D. Rose*

In reply to the specific questions posed by Wyllie and Rose, we would like to make the following comments:

First, we are of course not convinced on the basis of our rather limited experimental evidence that there is *never* a genuine variation of the saturation exponent, n, with saturation. Our own data on several consolidated sandstone cores do not show any evidence of this variation, even in the region close to irreducible water, where the theory of Wyllie and Rose would indicate that n should approach a value of minus infinity. (See Fig. 4 in Wyllie and Rose's forthcoming paper, which the authors have kindly furnished us.) This figure is of interest, also, in that it indicates that for cores having irreducible waters of less than 30%, n is approximately constant with saturation until the water saturation reaches a value not greatly different from irreducible water. Most of the material which we worked with had irreducible waters of less than 30%. This variation close to the irreducible water saturation, which is postulated by Wyllie and Rose, could not be expected to be detected by our experiments.

In answer to the second question, some of the results which we discarded indicated saturation exponents as high as six. However, as was stated in our paper, the criterion used for the reliability of the data was not the value of the saturation exponent, but the constancy of this value as obtained on different sections of the same core. If large and systematic variations in n were obtained for various sections of the core from top to bottom, this was taken to mean that the average brine saturation obtained for the entire core was not the same as the saturation in the individual sections. If this is so, a plot of resistance vs. an incorrect saturation would of course be meaningless.

Regarding the average value of the saturation exponent for consolidated and unconsolidated media, we can only reiterate that in our limited experience we have never observed a saturation exponent which was significantly greater than two for consolidated material, whereas for unconsolidated material the values have nearly always been two or above. ★ ★ ★

# INDEX TO TRANSACTIONS VOLUME 186

(Plus reference to Articles and Editorials published in *Journal of Petroleum Technology* in 1949)


A

ALCORN, I. W.: Editorial, Jan. JPT

Application of the Capillary Pressure Method for the Determination of Oil Recovery, by Walter Rose (Tech. Note), 326

Application of the LaPlace Transformation to Flow Problems in Reservoirs, by A. F. van Everdingen and W. Hurst, 305

ARCHIE, G. E.: *Discussion of the Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 324

B

BABSON, E. C.: *Discussion of Estimation of Reserves and Water Drive from Pressure and Production History*, 97

BAILEY, C. R., DUNLAP, HENRY F., BILHARTZ, HARRELL L., and SHULER, ELLIS: *The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 259

Banausia — or the Greeks Had a Word for It, by Reese H. Taylor, Mar. JPT

BEACH, WALTER G.: *Travelling Block Deflector in Drilling Operations* (Tech. Note), Nov. JPT

Behavior of Binary, Ternary, and Multicomponent Systems at States Similar to Those Encountered in Condensate Fields, by B. H. Sage and W. N. Lacey, 143

BERGMAN, W. E., FISHER, H. B. and CARPENTER, P. G.: *Factors Involved in Removal of Sulphate from Drilling Muds by Barium Carbonate*, 197

BESSE, C. P. and OSBORNE, G. W.: *Gulf of Mexico Floating Drilling Tender*, 87

BILHARTZ, HARRELL L., SHULER, ELLIS, BAILEY, C. R., and DUNLAP, HENRY F.: *The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 259

BILLHEIMER, J. S., REAMER, H. H. and SAGE, B. H.: *Multiple Condensed Phases in the Decane-Tetralin-Bitumen System*, 279

BILLHEIMER, J. S., SAGE, B. H. and LACEY, W. N.: *Multiple Condensed Phases in the N-Pentane-Tetralin-Bitumen System*, 283

BILLHEIMER, J. S., YUNDT, C. G., SAGE, B. H. and LACEY, W. N.: *Multiple Condensed Phases in the Methane-Decane-Tetralin-Bitumen System*, 265

BINCKLEY, C. W., BURGESS, F. R., and HAYMAKER, E. R.: *Method of Establishing a Stabilized Back-Pressure Curve for Gas Wells Producing from Reservoirs of Extremely Low Permeability*, 71

Bottom Hole Flow Surveys for Determination of Fluid and Gas Movements in Wells, by C. R. Dale, 205

BOYD, JAMES: *Technology and Low Grade Mineral Deposits* (Editorial) Nov. JPT

BRANTLY, J. E.: *Suggested National Oil Policy* (Editorial), Sept. JPT

BRESTON, JOSEPH and HUGHES, RICHARD V.: *Relation Between Pressure and Recovery in Long Core Water Floods*, 100

BROKAW, ALBERT D.: *Correction of Gas Volumes for Compressibility and Temperatures*, 248

BROWNSCOMBE, E. R., and COLLINS, FRANCIS: *Estimation of Reserves and Water Drive from Pressure and Production History*, 92

BROWNSCOMBE, E. R., KIESCHNICK, W. F., JR., and MILLER, CHARLES C.: *A Calculation of the Effect of Production Rate Upon Ultimate Recovery by Solution Gas Drive*, 235

BRUCE, W. A. and ROSE, WALTER: *Evaluation of Capillary Character in Petroleum Reservoir Rock*, 127

BRYANT, F. S.: *Some Aspects of Unitization—California Oil and Gas Fields*, Feb. JPT

BULNES, A. C.: *Discussion of Theoretical Generalizations Leading to the Evaluation of Relative Permeability*, 125

BURTCHAELL, E. P.: *Reservoir Performance of a High Relief Pool*, 171

BURGESS, F. R., HAYMAKER, E. R., and BINCKLEY, C. W.: *Method of Establishing a Stabilized Back-Pressure Curve for Gas Wells Producing from Reservoirs of Extremely Low Permeability*, 71

C

Calculation of the Effect of Production Rate upon Ultimate Recovery by Solution Gas Drive, by Charles C. Miller, E. R. Brownscombe, and W. F. Kieschnick, Jr., 235

CALHOUN, JOHN C., JR., LEWIS, MAURICE, JR., and NEWMAN, R. C.: *Experiments on the Capillary Properties of Porous Solids*, 189

CALHOUN, JOHN C., JR., and LOPER, RAMOND G.: *The Effect of Well Spacing and Drawdown on Recovery from Internal Gas Drive Reservoirs*, 211

Capillary pressures and capillarity:
Calculation of permeability from, 39
Evaluation of character, 127
Experiments on retention of water, 189
Measurement by mercury, 39

Capillary Pressures — Their Measurement Using Mercury and the Calculation of Permeability Therefrom, by W. R. Purcell, 39

CARPENTER, P. G., BERGMAN, W. E. and FISHER, H. B.: *Factors Involved in Removal of Sulphate from Drilling Muds by Barium Carbonate*, 197

CARTER, D. V.: *Function of Petroleum Engineering Departments and Their Relationship to Management*, Sept. JPT

CLARK, J. B.: *A Hydraulic Process for Increasing the Productivity of Wells*, 1

CLARK, ROSCOE C., JR.: *Well Cementing at Low Temperatures* (Tech. Note) 328

COLLINS, FRANCIS and BROWNSCOMBE, E. R.: *Estimation of Reserves and Water Drive from Pressure and Production History*, 92

Conservation
of oil and gas in Pickton field, 55

COOKE, JOHN T. and ELKINS, LINCOLN F.: *Pilot Gas Injection — Its Conduct and Criteria for Evaluation*, 180

Coring
core recording, 33

Core Recorder, by Clark Millison, 33

Correction of Gas Volumes for Compressibility and Temperatures, by Albert D. Brokaw, 248

D

DALE, C. R.: *Bottom Hole Flow Surveys for Determination of Fluid and Gas Movements in Wells*, 205

Developments in the Petroleum Field in Canada and Their Impact on the Economy of Canada, by H. H. Hewetson, Mar. JPT

Directional Drilling — Trespass to Technique (Editorial), by Howard C. Pyle, Oct. JPT

DOLL, H. G.: *Introduction to Induction Logging and Application to Logging of Wells Drilled with Oil Base Mud*, 148

Drilling
equipment, for offshore operation, 87
equipment, semi-automatic, 27
muds, removal of sulphate from, 197
tenders, 87

DUNLAP, HENRY F., BILHARTZ, HARRELL L., SHULER, ELLIS, and BAILEY, C. R.: *The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 259

E

Effects of Transient Conditions in Gas Reservoirs, by D. T. MacRoberts, 36

Effect of Well Spacing and Drawdown on Recovery from Internal Gas Drive Reservoirs, by Raymond G. Loper and John C. Calhoun, Jr., 211

Electrical Computer for Solving Phase Equilibrium Problems, by M. Muskat and J. M. McDowell, 291

Electric logging
effect of brine saturation, 259
electrochemical component, 17
induction logging, 148
resistivity relationships, 14
S. P. curves, analysis, 17

ELFRINK, E. B., SANDBERG, C. R. and POLLARD, T. A.: *New Compressibility Correlation for Natural Gases and Application to Estimates of Gas-In-Place*, 219

ELKINS, LINCOLN F. and COOKE, JOHN T.: *Pilot Gas Injection—Its Conduct and Criteria for Evaluation*, 180

ELKINS, L. E.: Editorial, Feb. JPT

ELKINS, L. E.: *A Preface to the Dues Referendum* (Editorial), Apr. JPT

ELKINS, L. E.: Editorial, Mar. JPT

ELKINS, L. E.: *Vote Yes on Dues Increase* (Editorial), May JPT

Engineering Profession and the Socialization of Industry, by L. E. Young, Nov. JPT

Estimation of Reserves and Water Drive from Pressure and Production History, by E. R. Brownscombe and Francis Collins, 92

Evaluation of Capillary Character in Petroleum Reservoir Rock, by Walter Rose and W. A. Bruce, 127

Experiments on the Capillary Properties of Porous Solids, by John C. Calhoun, Jr., Maurice Lewis, Jr., and R. C. Newman, 189

Factors Involved in Removal of Sulphate from Drilling Muds by Barium Carbonate, by W. E. Bergman, H. B. Fisher and P. G. Carpenter, 197

F

FISHER, H. B., CARPENTER, P. G., and BERGMAN, W. E.: *Factors Involved in Removal of Sulphate from Drilling Muds by Barium Carbonate*, 197

FITTING, RALPH U., JR.: *Discussion of Pilot Gas Injection—Its Conduct and Criteria for Results*, 188

FITZGERALD, P. E.: *Discussion of a Hydraulic Process for Increasing the Productivity of Wells*, 7

Formation fracture, 1

Fundamental Forces Involved in the Use of Oil Well Packers, by Jack D. Webber, 271

Functon of Petroleum Engineering Departments and Their Relationship to Management, by D. V. Carter, Sept. JPT

G

Gas
back-pressure testing of wells, 71
compressibility correlation for, 219
conservation in Pickton field, 55
correction of volumes for compressibility and temperature, 248
determination of movement in wells, 205
hydrates, 66, 83
injection, 180
reservoirs, effects of transient conditions in, 37
solution gas drive, 235

Gas Hydrates of Carbon Dioxide—Methane Mixture, by Carl H. Unruh and Donald L. Katz, 83

GLENN, A. H. and GRAHAM, J. E.: *Outline of Weather and Wave Forecasting Techniques*, 49

GRAHAM, J. E. and GLENN, A. H.: *Outline of Weather and Wave Forecasting Techniques*, 49

Gravity drainage, 171

Gulf of Mexico Floating Drilling Tender, by C. P. Besse and G. W. Osborne, 87

GUYOD, HERBERT: *Discussion of a Quantitative Analysis of the Electrochemical Component of the S. P. Curve*, 25

GUSTAFSON, J. D.: *Recent Canadian Oil Developments*, Dec. JPT

H

HAWKINS, WALLACE: *Oil and Gas Conservation*, 1949, Jun. JPT

HAYMAKER, E. R., BINCKLEY, C. W., and BURGESS, F. R.: *Method of Establishing a Stabilized Back-Pressure Curve for Gas Wells Producing from Reservoirs of Extremely Low Permeability*, 71

HEWETSON, H. H.: *Developments in the Petroleum Field in Canada and Their Impact on the Economy of Canada*, Mar. JPT

HORRER, PAUL L.: *Wave Forces Computed for a Typical Offshore Drilling Site*, 299

HUGHES, RICHARD V. and BRESTON, JOSEPH N.: *Relation Between Pressure and Recovery in Long Core Water Floods*, 100

HURST, W. and VAN EVERDINGEN, A. F.: *The Application of the Laplace Transformation to Flow Problems in Reservoirs*, 305

Hydrates
carbon dioxide-methane mixtures, 83
methane, 66

Hydraulic Process for Increasing the Productivity of Wells, by J. B. Clark, 1

Hydrocarbon Mixtures
computor for equilibrium problems, 291
phase behavior, 143, 265, 279, 283

I

Induction logging, 148

Introduction to Induction Logging and Application to Logging of Wells Drilled with Oil Base Mud, by H. G. Doll, 148

K

KATZ, DONALD L. and KOBAYASHI, RIKI: *Methane Hydrate at High Pressure*, 66

KATZ, DONALD L. and UNRAH, CARL H.: *Gas Hydrates of Carbon Dioxide—Methane Mixture*, 83

KAVELER, H. H.: *More Banausia* (Editorial), Dec. JPT

KELLER, W. O. and MORSE, R. A.: *Some Examples of Fluid Flow Mechanism in Limestone Reservoirs*, 224

KIESCHNICK, W. F., JR., MILLER, CHARLES C., and BROWNSCOMBE, E. R.: *A Calculation of the Effect of Production Rate Upon Ultimate Recovery by Solution Gas Drive*, 235

KOBAYASHI, RIKI and KATZ, DONALD L.: *Methane Hydrate at High Pressure*, 66

L

LACEY, W. N. BILLHEIMER, J. S., and SAGE, B. H.: *Multiple Condensed Phases in the N-Pentane-Tetralin-Bitumen System*, 283

LACEY, W. N., BILLHEIMER, J. S., YUNDT, C. G., and SAGE, B. H.: *Multiple Condensed Phases in the Methane-Decane-Tetralin-Bitumen System*, 265

LACEY, W. N. and SAGE, B. H.: *Behavior of Binary, Ternary, and Multicomponent Systems at States Similar to Those Encountered in Condensate Fields*, 143

LEWIS, MAURICE, JR., NEWMAN, R. C., and CALHOUN, JOHN C., JR.: *Experiments on the Capillary Properties of Porous Solids*, 189

Liquid Fuels from Coal and Oil Shales, by George Roberts, Jr. and Paul R. Schultz, Sept. JPT

LIVERMORE, GEORGE P.: *Place of the Engineer in the Drilling Industry*, Apr. JPT

LOPER, RAYMOND G. and CALHOUN, JOHN C., JR.: *The Effect of Well Spacing and Drawdown on Recovery from Internal Gas Drive Reservoirs*, 211

M

MACROBERTS, D. T.: *Effects of Transient Conditions in Gas Reservoirs*, 36

MCDOWELL, J. M. and MUSKAT, M.: *An Electrical Computer for Solving Phase Equilibrium Problems*, 291

Mercury injection
to determine capillary pressures, 39

Meteorology
application to offshore operation, 49

Method of Embedding Large Cores in Plastic for Fluid Flow Studies, by Penn. State Coll. Pet. and Nat. Gas Div., Aug. JPT

Middle Eastern Oil and Its Importance to the World, by John R. Suman, Jan. JPT

MILLER, CHARLES C., BROWNSCOMBE, E. R., and KIESCHNICK, W. F., JR.: *A Calculation of the Effect of Production Rate upon Ultimate Recovery by Solution Gas Drive*, 235

MILLISON, CLARK: *The Core Recorder*, 33

MOORE, CARL A.: *Preparation of Lantern Slide Copy*, Sept. JPT

More Banausia (Editorial), by H. H. Kaveler, Dec. JPT

MORSE, R. A. and KELLER, W. O.: *Some Examples of Fluid Flow Mechanism in Limestone Reservoirs*, 224

MUSKAT, MORRIS: *Discussion of Estimation of Reserves and Water Drive from Pressure and Production History*, 98

MUSKAT, MORRIS: *Production Research—Present and Future*, Jul. JPT

MUSKAT, M. and MCDOWELL, J. M.: *Electrical Computer for Solving Phase Equilibrium Problems*, 291

Method of Establishing a Stabilized Back-Pressure Curve for Gas Wells Producing from Reservoirs of Extremely Low Permeability, by E. R. Haymaker, C. W. Binckley, and F. R. Burgess, 71

Multiple Condensed Phases in the Decane-Tetralin-Bitumin System, by J. S. Billheimer, H. H. Reamer and B. H. Sage, 279

Multiple Condensed Phases in the Methane-Decane-Tetralin-Bitumen System, by J. S. Billheimer, C. G. Yundt, B. H. Sage and W. N. Lacey, 265

Multiple Condensed Phases in the N-Pentane-Tetralin-Bitumen System, by J. S. Billheimer, B. H. Sage and W. N. Lacey, 283

Methane Hydrate at High Pressure, by Riki Kobayashi and Donald L. Katz, 66

N

New Compressibility Correlation for Natural Gases and Application to Estimates of Gas-in-Place, by E. B. Elfrink, C. R. Sandberg, and T. A. Pollard, 219

NEWMAN, R. C., CALHOUN, JOHN C., JR., and LEWIS, MAURICE, JR.: *Experiments on the Capillary Properties of Porous Solids*, 189

O

Oceanography
application to offshore operation, 49, 299

Oil and Gas Conservation, 1949, by Wallace Hawkins, June JPT

Oil base mud
use with induction logging, 148

OSBORNE, G. W. and BESSE, C. P.: *Gulf of Mexico Floating Drilling Tender*, 87

Outline of Weather and Wave Forecasting Techniques, by A. H. Glenn and J. E. Graham, 49

P

Packers
fundamentals involved in use, 271
requirements for formation fracture, 3

PARSONS, C. P.: *Discussion of a Hydraulic Process for Increasing the Productivity of Wells*, 7

PATNODE, H. W.: *Relationship of Drilling Mud Resistivity to Mud Filtrate Resistivity*, 14

Penn State Coll. Pet. and Nat. Gas Div., Method of Embedding Large Cores in Plastic for Fluid Flow Studies, Aug. JPT

Performance of the Ten Section Oil Field, by W. Tempelaar Lietz, 251

Permeability
calculation from capillary pressures, 39
distribution, use of in water flood calculations, 9
relative, evaluation of, 111

Permeability Distribution in Water Flood Calculations, by W. E. Stiles, 9

Pickton field, Texas, 55

Pilot Gas Injection — Its Conduct and Criteria for Evaluation, by Lincoln F. Elkins and John T. Cooke, 180

Place of the Engineer in the Drilling Industry, by George P. Livermore, Apr. JPT

POLLARD, T. A., ELFRINK, E. B., and SANDBERG, C. R.: *A New Compressibility Correlation for Natural Gases and Application to Estimates of Gas-In-Place*, 219

Preface to the Dues Referendum (Editorial), by L. E. Elkins, Apr. JPT

Preparation of Colored Lantern Slides, by G. Zuloaga, Sept. JPT

Preparation of Lantern Slide Copy, by Carl A. Moore, Sept. JPT

Pressure
relation to recovery in water floods, 100
use of pressure history in reserve estimation, 92

Private Financing of Oil Producing Properties, by C. L. Rice, Jr., Jan. JPT

Production of Oil Under Unitization in Wertz Dome Field, Wyoming, by E. A. Swendenborg, 163

Production Research—Present and Future, by Morris Muskat, July JPT

PURCELL, W. R.: *Capillary Pressures — Their Measurement Using Mercury and the Calculation of Permeability Therefrom*, 39

PYLE, HOWARD C.: *Directional Drilling — Trespass to Technique* (Editorial), Oct. JPT

Q

Quantitative Analysis of the Electrochemical Component of the S. P. Curve, by M. R. J. Wyllie, 17

R

REAMER, H. H., SAGE, B. H., and BILLHEIMER, J. S.: *Multiple Condensed Phases in the Decane-Tetralin-Bitumen System*, 279

Recent Canadian Oil Developments, by J. D. Gustafson, Dec. JPT

REISTLE, CARL E., JR.: *Reservoir Engineering and Conservation* (Editorial), Jun. JPT

Relation between Electrical Resistivity and Brine Saturation in Reservoir Rocks, by Henry F. Dunlap, Harrell L. Bilhartz, Ellis Shuler and C. R. Bailey, 259

Relation between Pressure and Recovery in Long Core Water Floods, by Joseph N. Breston and Richard V. Hughes, 100

Relationship of Drilling Mud Resistivity to Mud Filtrate Resistivity, by H. W. Patnode, 14

Reserves
estimation of, 92
gas, estimation, compressibility, correlation, 219

Reservoir Engineering and Conservation (Editorial), by Carl E. Reistle, Jr., June JPT

Reservoir performance
gravity drive type, 171
limestone reservoirs, examples, 224
Pickton field, 55
Ten Section field, 251
Wertz Dome field, 163

Reservoir Performance of a High Relief Pool, by E. P. Burtchaell, 171

Resistivities
of drilling mud, 14
relation to brine saturation, 259
of mud filtrates, 14

RICE, C. L., JR.: *Private Financing of Oil Producing Properties*, Jan. JPT

ROBERTS, GEORGE, JR. and SCHULTZ., PAUL R.: *Liquid Fuels from Coal and Oil Shales*, Sept. JPT

ROSE, WALTER: *Application of the Capillary Pressure Method for the Determination of Oil Recovery* (Tech. Note), 326

ROSE, WALTER: *Discussion of Capillary Pressures, Their Measurement Using Mercury and the Calculation of Permeability Therefrom*, 46

ROSE, WALTER: *Theoretical Generalizations Leading to the Evaluation of Relative Permeability*, 111

ROSE, WALTER and BRUCE, W. A.: *Evaluation of Capillary Character in Petroleum Reservoir Rock*, 127

ROSE, WALTER D., and WYLLIE, M. R. J.: *Discussion of The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 325

ROSE, WALTER and WYLLIE, M. R. J.: *Theoretical Description of Wetting Liquid Relative Permeability* (Tech. Note), Sept. JPT

RYDER, HARRY M.: *Discussion of Relation Between Pressure and Recovery in Long Core Water Floods*, 109

S

SAGE, B. H., BILLHEIMER, J. S. and REAMER, H. H.: *Multiple Condensed Phases in the Decane-Tetralin-Bitumen System*, 279

SAGE, B. H. and LACEY, W. N.: *Behavior of Binary, Ternary, and Multicomponent Systems at States Similar to those Encountered in Condensate Fields*, 143

SAGE, B. H., LACEY, W. N., and BILLHEIMER, J. S.: *Multiple Condensed Phases in the N-Pentane-Tetralin-Bitumen System*, 283

SAGE, B. H., LACEY, W. N., BILLHEIMER, J. S., and YUNDT, C. G.: *Multiple Condensed Phases in the Methane-Decane-Tetralin-Bitumen System*, 265

SANDBERG, C. R., POLLARD, T. A., and ELFRINK, E. B.: *A New Compressibility Correlation for Natural Gases and Application to Estimates of Gas-In-Place*, 219

SAUNDERS, G. E.: *Discussion of Factors Involved in Removal of Drilling Muds by Barium Carbonate*, 203

SCHULTZ, PAUL R. and ROBERTS, GEORGE, JR.: *Liquid Fuels from Coal and Oil Shales*, Sept. JPT

SELLS, H. R.: *Discussion of Method of Establishing a Stabilized Back-Pressure Curve for Gas Wells Producing from Reservoirs of Extremely Low Permeability*, 82

Semi-Automatic Power Operated Drilling Equipment, by M. E. True and B. L. Stone, 27

SHULER, ELLIS, BAILEY, C. R., DUNLAP, HENRY F., and BILHARTZ, HARRELL L.: *The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 259

SIMPSON, R. E., SMITH, J. W., YUST, C. S. and WELSH, J. R.: *A Study of Oil and Gas Conservation in the Pickton Field*, 55

SMITH, J. W., YUST, C. S., WELSH, J. R. and SIMPSON, R. E.: *A Study of Oil and Gas Conservation in the Pickton Field*, 55

SOLLIDAY, A. L.: *When Do We Need a Synthetic Fuel Industry?* Oct. JPT

Some Aspects of Our Future Mineral Supplies, by W. E. Wrather, Feb. JPT

Some Aspects of Unitization — California Oil and Gas Fields, by F. S. Bryant, Feb. JPT

Some Examples of Fluid Flow Mechanisms in Limestone Reservoirs, by W. O. Keller and R. A. Morse, 224

STILES, W. E.: *Use of Permeability Distribution in Water Flood Calculations*, 9

STONE, B. L. and TRUE, M. E.: *Semi-Automatic Power Operated Drilling Equipment*, 27

Study of Oil and Gas Conservation in the Pickton Field, by J. R. Welsh, R. E. Simpson, J. W. Smith and C. S. Yust, 55

Suggested National Oil Policy (Editorial), by J. E. Brantly, Sept. JPT

SUMAN, JOHN R.: *Middle Eastern Oil and its Importance to the World*, Jan. JPT

SUTER, HANS H.: *We the Banausians* (Editorial), July JPT

SWEDENBORG, E. A.: *Production of Oil Under Unitization in Wertz Dome Field, Wyoming*, 163

T

TAYLOR, REESE H.: *Banausia — or the Greeks Had a Word for It*, Mar. JPT

Technology and Low Grade Mineral Deposits (Editorial), by James Boyd, Nov. JPT

TEMPELAAR, LIETZ W.: *The Performance of the Ten Section Oil Field*, 251

Theoretical Description of Wetting Liquid Relative Permeability (Tech. Note), by Walter Rose and M. R. J. Wyllie, Sept. JPT

Theoretical Generalizations Leading to the Evaluation of Relative Permeability, by Walter Rose, 111

THORNTON, OWEN: *Valuation of Relative Permeability* (Tech. Note), 329

Travelling Block Deflector in Drilling Operations (Tech. Note), by Walter G. Beach, Nov. JPT

TRUE, M. E. and STONE, B. L.: *Semi-Automatic Power Operated Drilling Equipment*, 27

U

UNRUH, CARL H. and KATZ, DONALD L.: *Gas Hydrates of Carbon Dioxide—Methane Mixture*, 83

Valuation of Relative Permeability (Tech. Note), by Owen Thornton, 329

V

VAN DYKE, O. W.: *Discussion of Factors Involved in Removal of Sulphate From Drilling Muds*, 203

VAN EVERDINGEN, A. F. and HURST, W.: *The Application of the Laplace Transformation to Flow Problems in Reservoirs*, 305

Vote Yes on Dues Increase (Editorial), by L. E. Elkins, May JPT

W

Water Drive
estimation of, 92

Water flooding
calculations, 9
study by long cores, 100

WATSON, C. P.: *California Post-War Production and Demand*, Feb. JPT

Wave Forces Computed for a Typical Offshore Drilling Site, by Paul L. Horrer, 299

We the Banausians (Editorial), by Hans H. Suter, July JPT

Weather forecasting, 49

WEBBER, JACK C.: *Fundamental Forces Involved in the Use of Oil Well Packers*, 271

Well Cementing at Low Temperatures (Tech. Note), by Roscoe C. Clark, Jr., 328

Well spacing, 211

WELSH, J. R., SIMPSON, R. E., SMITH, J. W. and YUST, C. S.: *A Study of Oil and Gas Conservation in the Pickton Field*, 55

Wertz Dome field, Wyoming, 163

When Do We Need a Synthetic Fuel Industry?, by A. L. Solliday, Oct. JPT

WILLIAMS, MILTON: *Discussion of a Quantitative Analysis of the Electrochemical Component of the S. P. Curve*, 24

WRATHER, W. E.: *Some Aspects of Our Future Mineral Supplies*, Feb. JPT

WYLLIE, M. R. J. and ROSE, WALTER D.: *Discussion of The Relation Between Electrical Resistivity and Brine Saturation in Reservoir Rocks*, 325

WYLLIE, M. R. J.: *A Quantitative Analysis of the Electrochemical Component of the S. P. Curve*, 17

WYLLIE, M. R. J. and ROSE, WALTER: *Theoretical Description of Wetting Liquid Relative Permeability* (Tech. Note), Sept. JPT

Y

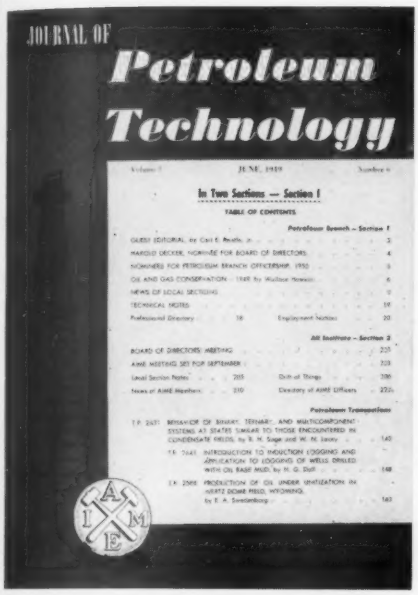
YOUNG, L. E.: *Engineering Profession and the Socialization of Industry*, Nov. JPT

YUNDT, C. G., SAGE, B. H., LACEY, W. N., and BILLHEIMER, J. S.: *Multiple Condensed Phases in the Methane-Decane-Tetralin-Bitumen System*, 265

YUST, C. S., WELSH, J. R. SIMPSON, R. E., and SMITH, J. W.: *A Study of Oil and Gas Conservation in the Pickton Field*, 55

Z

ZULOAGA, G.: *Preparation of Colored Lantern Slides*, Sept. JPT ★ ★ ★




# HOW PETROLEUM TECHNOLOGY SERVES YOU AS AN ADVERTISER

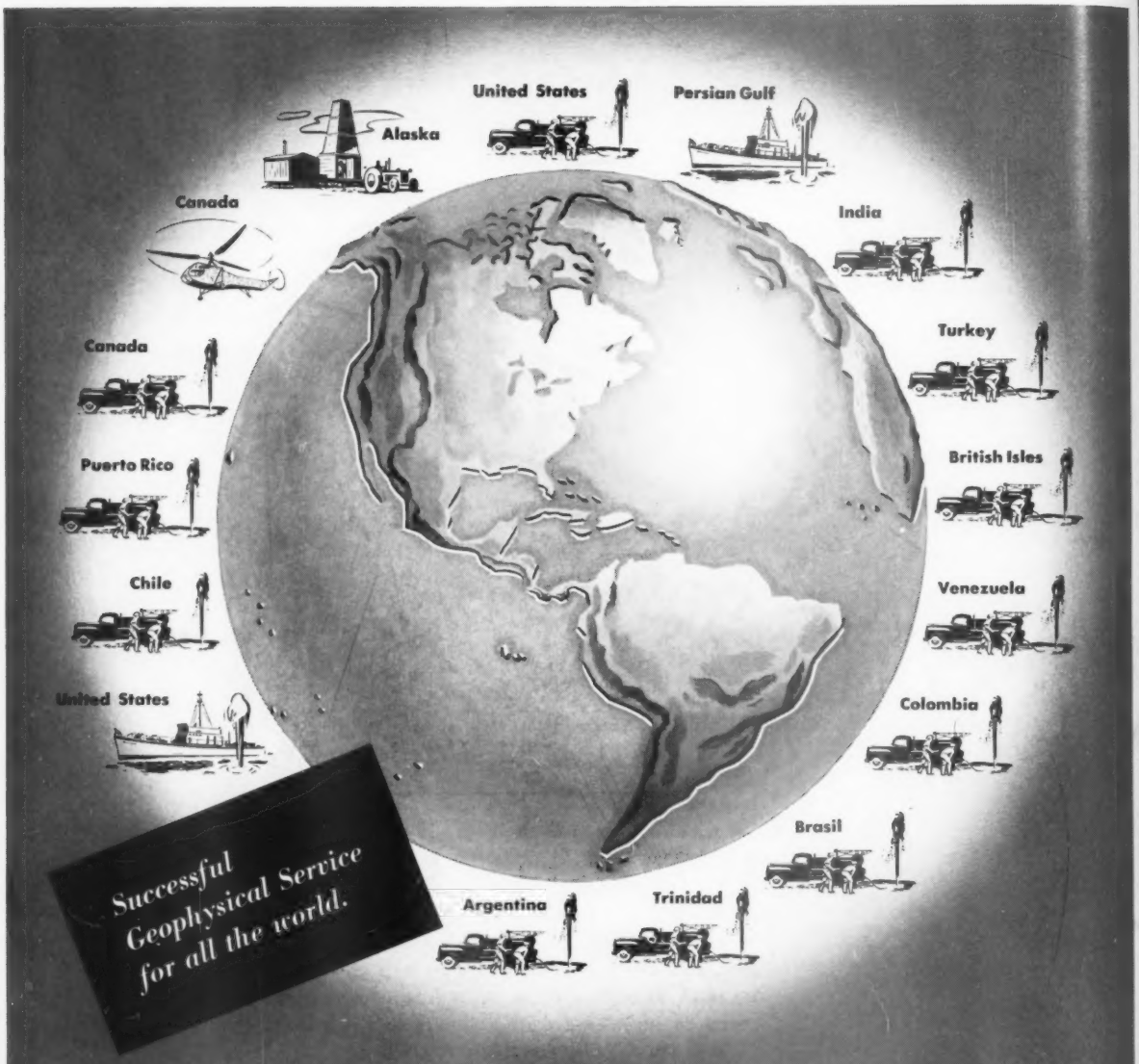
## SELECTED, INFLUENTIAL READERS

**Membership in the Petroleum Branch of AIME is conferred only on those who demonstrate their qualifications to practice petroleum engineering. This guarantees PETROLEUM TECHNOLOGY selected readers with a common interest. As exploration-drilling-production engineers and executives these readers *exert great influence* on the purchase of equipment and services. Throughout the industry they specify or approve most of these purchases, and every impression you make on them through advertising helps your sales program. PETROLEUM TECHNOLOGY provides a *direct approach* for you to impress a concentration of these influential men because it is published specifically for them.**

## EDITORIAL QUALITY CREATES READERSHIP

**The AIME publishes only those technical papers which are significant contributions to petroleum engineering literature. This careful screening makes each paper authoritative, and a current knowledge of the literature is vital to the practitioner. As a vehicle for this literature, each issue of PETROLEUM TECHNOLOGY receives thorough study from its readers. It is a reference work to be kept and frequently consulted because it represents an actual aid in the solution of daily problems. This close readership and continuous attention makes PETROLEUM TECHNOLOGY a valuable advertising medium for companies serving the exploration-drilling-production industry.**

# BUDGET PETROLEUM TECHNOLOGY FOR 1950




# UNITED

## GEOPHYSICAL COMPANY

SEISMOGRAPH • GRAVIMETER • MAGNETOMETER

Herbert Hoover, Jr. President

595 EAST COLORADO ST., PASADENA, CALIFORNIA, U.S.A.

TULSA, HOUSTON, NEW YORK, FAIRBANKS, CALGARY

APARTADO 1085, CARACAS, VENEZUELA

RIO DE JANEIRO, BRASIL • SANTIAGO, CHILE • BOGOTA, COLOMBIA • BEIRUT, LEBANON

نعم